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August 1998 REMOTS®
Survey of HARS Remediation
Cells 1, 2, and 3

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ACKNOWLEDGMENTS

This report presents the results of a REMOTS® survey of remediation cells 1, 2 and 3 at the Historic Area Remediation Site (HARS). This survey was conducted in August 1998 by Science Applications International Corporation (SAIC) of Newport, RI, under Delivery Order 15 of SAIC's Indefinite Delivery Contract No. DACW51-97-D-0014 with the U.S. Army Corps of Engineers - New York District (NYD). Mr. Brian May is the manager of technical activities under the NYD contract; Dr. Scott McDowell is SAIC's program manager.

Logistical and planning support for the survey were provided by Mr. Brian May of the NYD, with assistance from Mr. Tim LaFontaine.

Mssrs. Ray Valente, Jason Infantino, Greg Roebuck and Ms. Melissa Swanson of SAIC were responsible for mobilizing the field equipment and conducting the survey operations aboard the Corps vessel M/V *Hayward*. The captain and crew of the M/V *Hayward* are commended for their skill in vessel handling and dedication during long hours of field operations.

Ms. Melissa Swanson and Mr. Greg Roebuck analyzed the REMOTS® images and produced graphic data products for this report. The report was co-authored by Mr. Roebuck and Mr. Ray Valente. Dr. McDowell provided technical review of the report, while Mr. Tom Fox was responsible for report production.

1.0 INTRODUCTION

1.1 Background

Dredged material from the Port of New York and New Jersey historically has been placed in and around the Mud Dump Site (MDS), located in the open waters of the New York Bight six nautical miles east of Sandy Hook, New Jersey. Based on concerns about limited site capacity and the environmental effects of past disposal, EPA Administrator Carol Browner, Secretary of Transportation Frederico Pena, and Secretary of the Army Togo West, Jr. issued a "3 Party Letter" in 1996 announcing the closure of the MDS by September 1, 1997. The 3 Party Letter further states that simultaneous with the closure of the MDS, the site and surrounding areas which have been used historically for disposal of dredged material having elevated levels of chemical contaminants will be redesignated as the Historic Area Remediation Site, or HARS (Figure 1-1). On August 26, 1997, the U.S. Environmental Protection Agency (EPA) and the U.S. Army Corps of Engineers (USACE) finalized the rule providing for simultaneous closure of the MDS and designation of the HARS.

Region II of the EPA and the New York District (NYD) of the USACE together are responsible for managing the HARS to reduce the presently elevated contamination and toxicity of surface sediments to acceptable levels. The two agencies have prepared a Site Management and Monitoring Plan (SMMP) for the HARS which identifies a number of actions, provisions and practices to manage remediation activities and monitoring tasks (USACE/USEPA 1997). The planned remediation will consist of placing a one-meter "cap" layer of uncontaminated dredged material on top of the existing surface sediments within the 9 square mile Priority Remediation Area (PRA) of the HARS (Figure 1-2). The "remediation material" to be used for capping is defined as dredged material that meets current Category I standards and will not cause significant undesirable effects, including through bioaccumulation.

The main objective of the HARS SMMP is to ensure that placement of the remediation material does not result in any significant adverse environmental impacts but does result in sufficient modification (i.e., remediation) of currently unacceptable sediment chemistry and toxicity characteristics. Toward these ends, the SMMP includes a tiered monitoring program designed to focus both on the entire HARS and on each of the 9 individual remediation cells in the PRA. The monitoring to be undertaken at regular intervals includes high resolution bathymetry, sediment profile imaging (SPI), sediment coring, sediment chemistry and toxicity testing, tissue chemistry testing, benthic community analyses, and fish/shellfish surveys. Baseline surveys involving REMOTS® sediment-profile imaging and sediment planview photography were conducted in and around the HARS in 1995 and 1996 (SAIC 1996a and b). This report presents the results of a REMOTS® and planview survey designed to focus specifically on remediation cells 1, 2 and 3 of the HARS PRA (Figure 1-2).

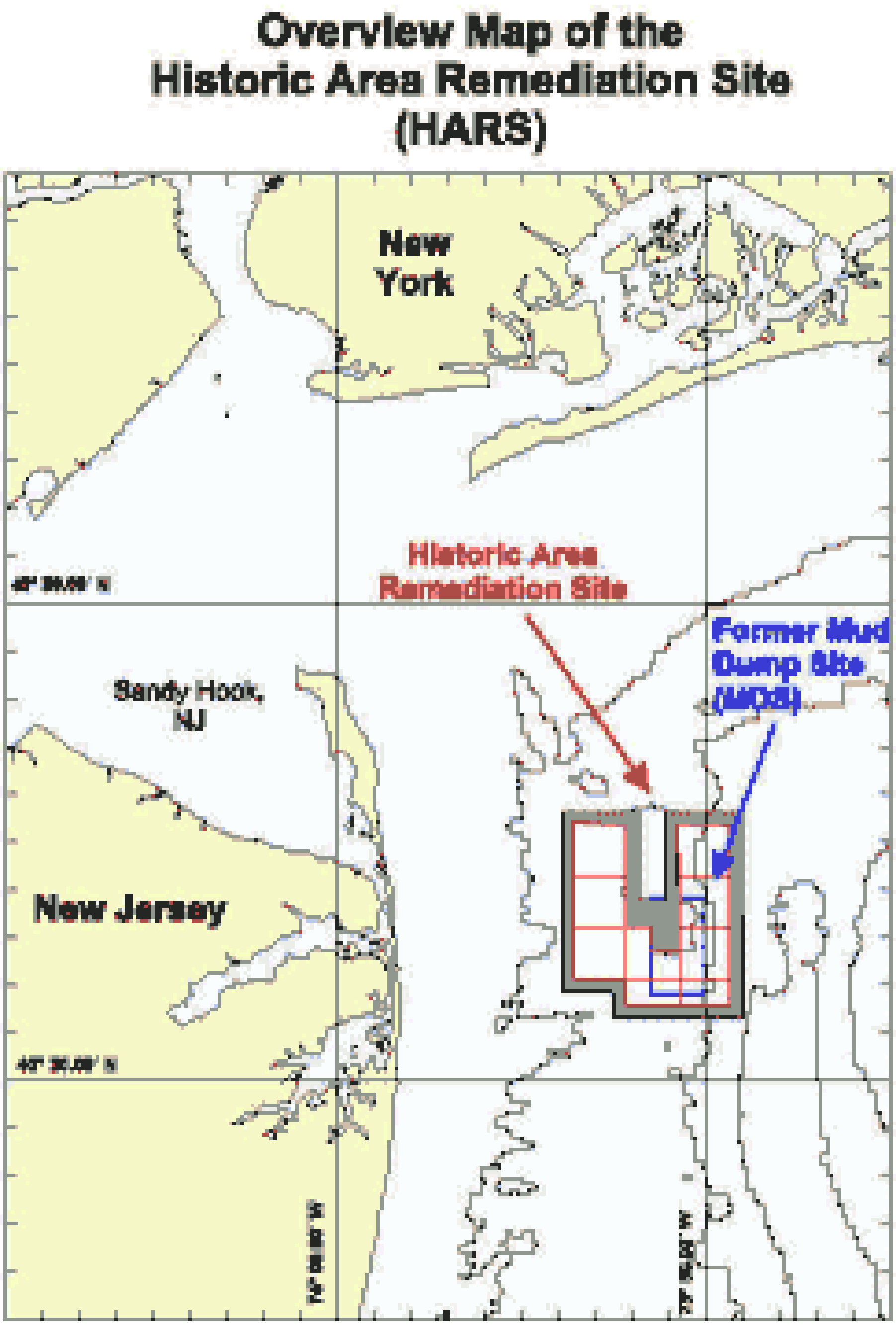


Figure 1-1. Overview map showing the locations of the Historic Area Remediation Site (HARS) and the former Mud Dump Site (MDS) in the New York Bight.

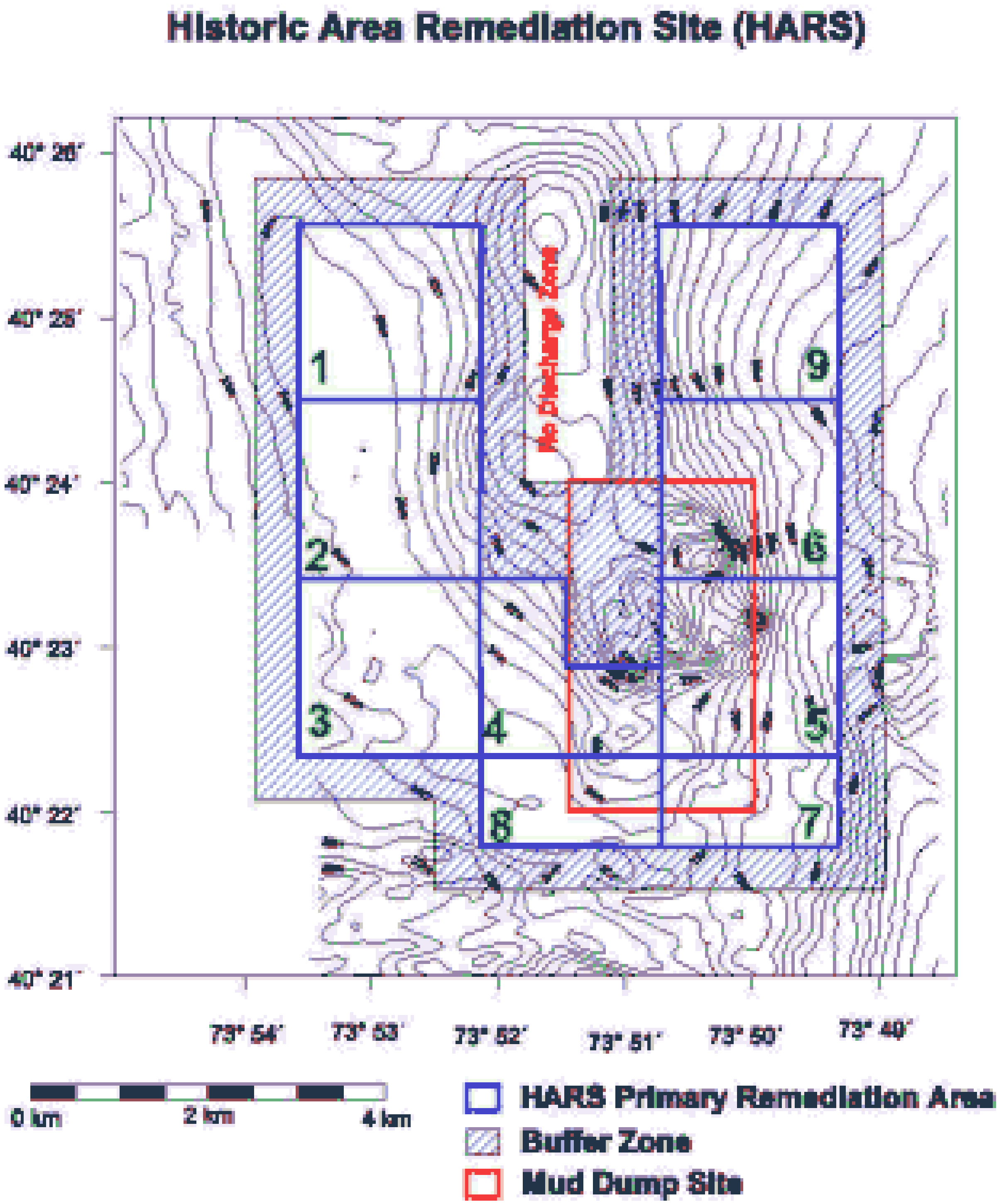


Figure 1-2. Map of the Historic Area Remediation Site (HARS), showing the former Mud Dump Site, the HARS buffer zone, the North Reference Area (NREF), and the nine individual remediation cells which comprise the HARS Priority Remediation Area (PRA). The bathymetric contours are based on hydrographic surveys conducted in August 1995 and May 1996.

The HARS SMMP specifies that monitoring is to occur not only within individual remediation cells, but also at nearby reference areas which have not yet been identified. The reference areas must be selected with care, because future assessments of environmental changes at the HARS will be based largely on comparisons with these areas. Generally speaking, reference areas should be located near and have characteristics similar to those of the impact area(s), while being far enough away so as not to experience the impact. In environmental monitoring programs like the one planned for the HARS, it is desirable to employ multiple reference areas for adequate statistical detection of impacts (Stewart-Oaten et al. 1986; Underwood 1992, 1994). At present there are two older reference areas which might be considered for use in future HARS monitoring. Both are located southwest of the former MDS and have been sampled extensively in past and on-going programs to monitor the environmental effects of dredged material disposal at the MDS. However, because the North Reference Area is located within the HARS buffer zone (Figure 1-2), it is considered unsuitable for continued use in future HARS monitoring. The South Reference Area is located far enough away from the HARS boundaries to be considered suitable for continued use; however, the predominant sediment type in this area is rippled sand. Because it is likely that remediation material placed in the HARS will consist of both fine-grained (i.e., silt-clay) and sandy sediments, future evaluations of the environmental effects of such placement should be based on comparisons with both fine-grained and sandy reference areas. Therefore, there exists a need to designate additional sandy and silt-clay reference areas within the New York Bight region to provide appropriate comparisons in future HARS monitoring efforts.

1.2 Objectives

The August 1998 REMOTS® survey of HARS remediation cells 1, 2 and 3 was designed to address the following two objectives:

1) Characterize seafloor conditions in the three remediation cells to provide a basis for evaluating future expected changes in sediment characteristics and benthic habitat quality as remediation material is placed in these cells over the coming years.

1) Obtain data on seafloor characteristics at selected locations in the vicinity of the HARS and evaluate the suitability of these locations for use as reference areas in future HARS monitoring efforts.

2.0 METHODS

2.1 Navigation

The August 1998 REMOTS® survey at the HARS was conducted aboard the USACE NYD's 125-ft vessel, M/V *Hayward*. SAIC installed its Portable Integrated Navigation and Survey System (PINSS) on the vessel to provide navigational support for the crew and to store survey data digitally. Vessel positioning at predetermined stations was accomplished using a Magnavox 4200D GPS positioning system interfaced to the PINSS. The PINSS utilized a Toshiba 3200DX personal computer to provide real-time navigation, as well as to collect position, depth, and time data for subsequent analyses. One to five-meter accuracy was achieved by applying a differential correction to the GPS signals from an FM modem receiving Differential Corrections Incorporated (DCI) premium service. Vessel position was displayed on two monitors, one for the survey navigator and the second for the helmsman to aid in steering the vessel toward target station locations. In addition, a Hewlett Packard 7475A plotter tracked the vessel's position during survey operations, allowing the navigator to assess the vessel's location relative to target station locations. An HP Thinkjet printer generated a hard copy of position fixes. Each fix incorporated time of day, the vessel's position in Latitude and Longitude and UTM coordinates, signal quality, and station and replicate identification.

All differential GPS navigation data were received, logged and displayed in the North American Datum 1983 (NAD 83) geographic coordinate system. While SAIC Standard Operating Procedures have previously involved applying a correction for an offset to NAD 27 prior to submission of coordinate data to the NYD, the coordinate data in this report are presented in NAD 1983 to conform with side-scan sonar, sediment grab sampling, and other data recently collected by SAIC.

A. Field Sampling Design

The area of interest for this survey encompassed HARS remediation cells 1, 2 and 3 and the adjoining buffer zone; this relatively large rectangular area (roughly 3.2 km x 8.2 km) is located immediately to the west and northwest of the former Mud Dump Site (Figure 1-2). Previous REMOTS® surveys conducted in October 1995 and May 1996 for the purpose of expanding the Mud Dump Site involved sampling portions of this area. The results of these previous surveys will be compared with those of the present survey in later sections of this report.

For the August 1998 REMOTS® survey, a total of two hundred and eight (208) stations were sampled in 6 field days during the period August 5 to 10. One hundred and fifty eight (158) of these stations were located in the area of interest consisting of HARS remediation cells 1, 2 and 3 and the associated buffer zone; the stations were spaced 400 meters apart in a series of rows and columns forming a rectangular sampling grid (Figure 2-1). Each row of stations was lettered sequentially A through U, and each

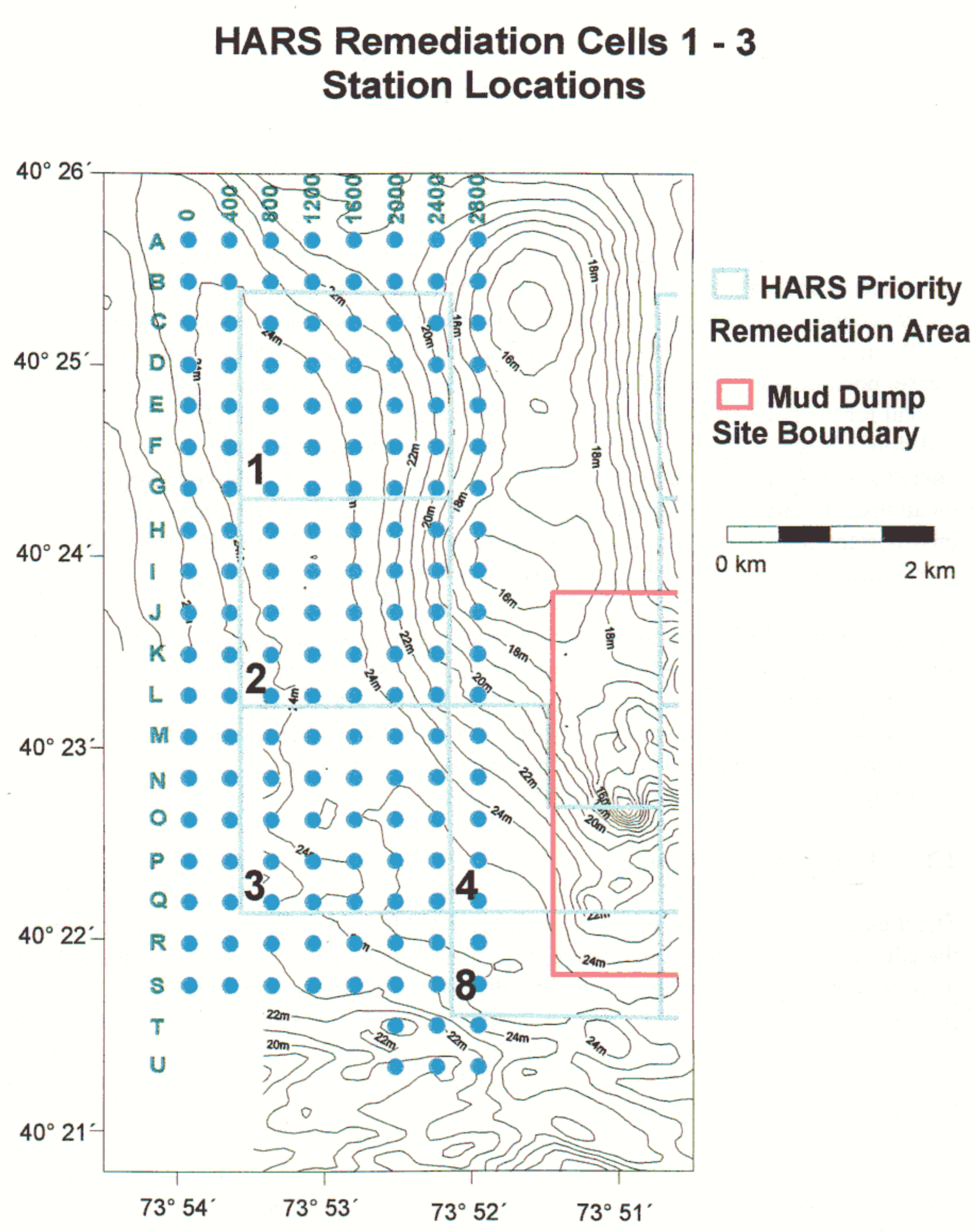


Figure 2-1. Location of 158 REMOTS® stations arranged in a rectangular grid pattern covering HARS remediation cells 1, 2, and 3 and the surrounding buffer zone.

column was labeled in increments of 400 meters starting with zero (0) at the western boundary (roughly longitude 73° 54') and ending with 2800 at the eastern boundary (roughly longitude 73°52'; Figure 2-1).

Ten (10) of the stations were located in the South Reference Area (SREF; Figure 2-2). As previously indicated, this reference area has been sampled in a number of previous REMOTS® surveys conducted at the Mud Dump Site, under both the 1997 Category II Capping Project (baseline and postdisposal) and the 1993 Dioxin Capping Monitoring Program (e.g., April 1994, July 1995, October 1996, and May 1997). The predominant sediment type at SREF is sand, which is characteristic of much of the inner continental shelf in the New York Bight region. Sampling at this reference area in the present survey and into the future will provide both continuity with past studies and an adequate basis for comparison with results from within the HARS.

The remaining forty (40) REMOTS® stations were located in four candidate reference areas, as follows (see Figure 2-2):

1) Thirteen (13) stations were sampled at candidate reference area NREF2, located at a depth of roughly 27 m (90 ft) near the Ambrose Tower, north of the HARS. A review of nautical charts suggested that medium sand occurred in this location; therefore, this candidate reference area was sampled to determine its suitability as a replacement for the sandy NREF reference area. As previously indicated, the NREF area was used extensively in the past but is no longer suitable because it is located within the HARS buffer zone (Figure 2-2).

1) Nine (9) stations were sampled within each of two candidate reference areas located within the Christiaensen Basin, northwest of the former Sewage Sludge Dump Site (also called the 12-mile site). The water depth at these two candidate reference areas, named R2 and NY6, was roughly 28 m (92 ft) and 31 m (102 ft), respectively. Both areas were sampled previously in a large, interdisciplinary study conducted by the National Oceanic and Atmospheric Administration (NOAA) from 1986 to 1989 to document environmental changes following cessation of sewage sludge dumping at the 12-mile site (NOAA 1995). The NOAA study found fine-grained sediments in these two areas; therefore, they were sampled in the present study for the purpose of determining their suitability for use as fine-grained reference areas in future HARS monitoring.

1) Nine (9) stations were sampled in candidate reference area DEEP-REF, located at a depth of roughly 60 m (197 ft) within the Hudson Canyon. Sampling in the New York Bight conducted by the U.S. Geological Survey (USGS) indicated that fine-grained sediments occurred in this area.

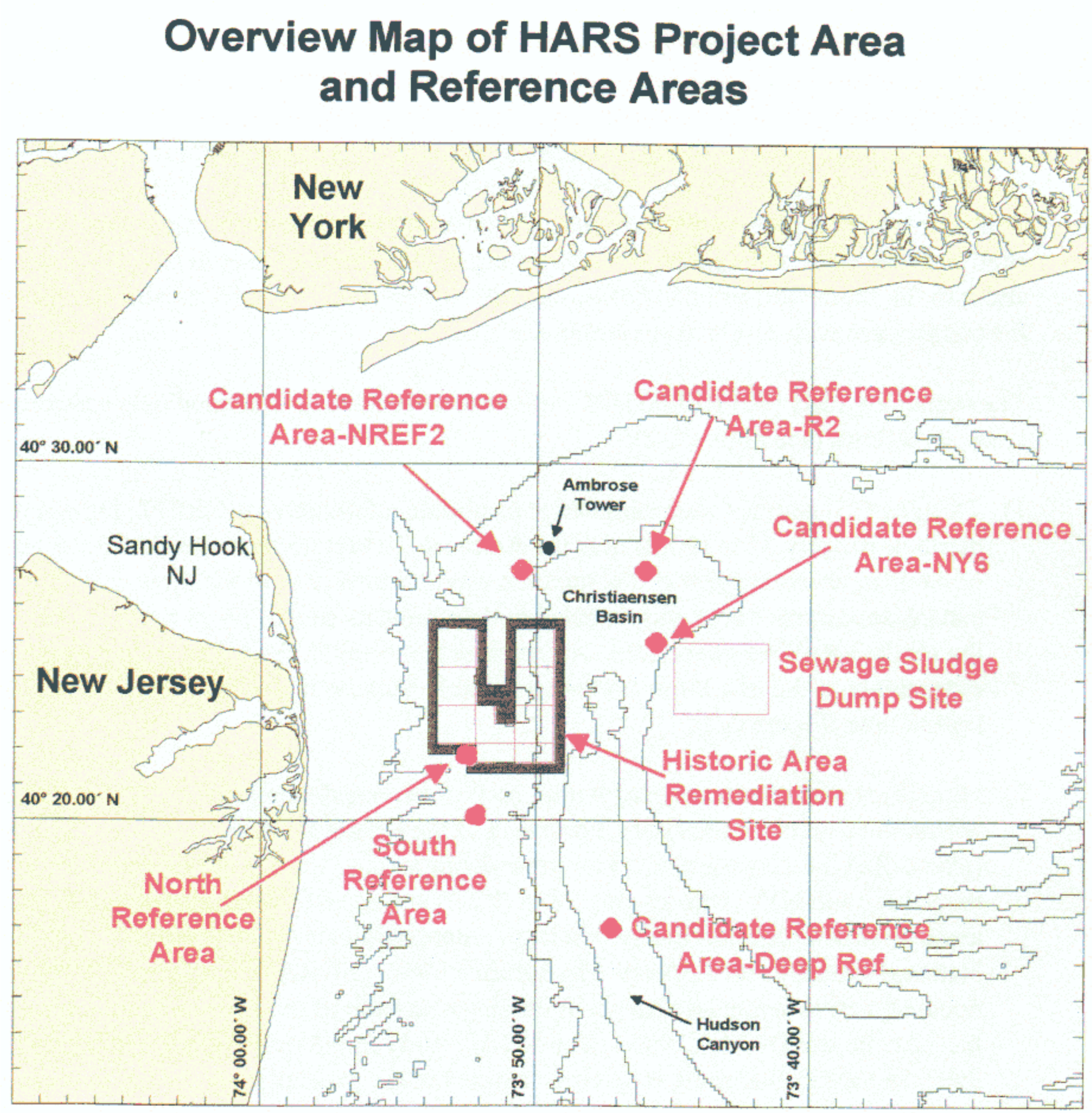


Figure 2-2. Map showing the locations of the North and South Reference Areas and four candidate reference areas (NREF2, R2, NY6, and DEEP-REF) in the New York Bight region surrounding the HARS.

The REMOTS® camera was lowered multiple times at each station in an attempt to collect at least two replicate REMOTS® images suitable for subsequent analysis. Color slide film was used and developed at the end of each field day to verify proper equipment operation and image acquisition.

A. Planview Photography

2.3.1 Planview Photograph Acquisition

Planview (i.e., horizontal plane) photographs of approximately 0.3 m^2 of the seafloor surface were obtained in conjunction with the REMOTS® images. The photographs were acquired with a PhotoSea 1000a 35mm Underwater Camera System and a PhotoSea 1500s Strobe Light attached to the REMOTS® camera frame. The photographs were taken immediately prior to the landing of the frame, providing an undisturbed record of the sediments before penetration of the REMOTS® prism. Once the camera frame was lifted above the sediments, the PhotoSea camera system automatically cycled film and recharged the strobe in preparation for the next photograph. In this manner, a corresponding planview photograph usually was obtained for each REMOTS® image acquired. However, in the present survey, planview photographs were not obtained at 22 of the 158 REMOTS® stations located in the HARS due to a camera malfunction.

2.3.2 Planview Photograph Analysis

Analysis of the planview images included screening all the replicates taken at the stations sampled. Poor water clarity and lack of contrast eliminated some of the images from further consideration. Of the remaining, a representative collection was made, which included one image from each set of station replicates successfully photographed.

The purpose of the planview image analysis was to supplement the more detailed and comprehensive REMOTS® characterization of the seafloor. The planview analysis consisted of qualitative descriptions of key sediment characteristics (e.g., sediment type, bedforms and biological features) based on careful scrutiny of the projected 35-mm slides. Since the surface sediment descriptions were based on visual observations and therefore are somewhat subjective, only the obvious presence of rock, gravel, sand and/or fines was noted. Likewise, the presence of shell debris and any evidence of epifaunal or infaunal organisms (e.g., tubes, burrow openings, etc.) were recorded. Recent dredged material was evident from black, grey or rust-colored deposits of poorly sorted or overconsolidated sediments. The presence of dredged material from past disposal was sometimes indicated by angular rocks and/or anthropogenic materials. A scale bar was not present in the photographs; however, each photograph covers an area of seafloor measuring roughly 0.4 m x 0.7 m (roughly 0.3 m^2).

2.4 REMOTS® Sediment-Profile Imaging

REMOTS® is a formal and standardized technique for sediment-profile imaging and analysis (Rhoads and Germano 1982; 1986). A Benthos Model 3731 Sediment Profile Camera (Benthos, Inc., North Falmouth, MA) was used in this study (Figure 2-3). The camera is designed to obtain *in situ* profile images of the top 20 cm of sediment. Functioning like an inverted periscope, the camera consists of a wedge-shaped prism with a front face plate and a back mirror mounted at a 45-degree angle to reflect the profile of the sediment-water interface facing the camera. The prism is filled with distilled water, the assembly contains an internal strobe used to illuminate the images, and a 35-mm camera is mounted horizontally on top of the prism. The prism assembly is moved up and down into the sediments by producing tension or slack on the winch wire. Tension on the wire keeps the prism in the up position, out of the sediments.

2.4.1 REMOTS® Image Acquisition

The camera frame is lowered to the seafloor at a rate of about 1 m/sec (Figure 2-3). When the frame settles onto the bottom, slack on the winch wire allows the prism to penetrate the seafloor vertically. A passive hydraulic piston ensures that the prism enters the bottom slowly (approximately 6 cm/sec) and does not disturb the sediment-water interface. As the prism starts to penetrate the seafloor, a trigger activates a 13-second time delay on the shutter release to allow maximum penetration before a photo is taken. A Benthos Model 2216 Deep Sea Pinger is attached to the camera and outputs a constant 12 kHz signal of one ping per second; upon discharge of the camera strobe, the ping rate doubles for 10 seconds. Monitoring the signal output on deck provides confirmation that a successful image was obtained. Because the sediment photographed is directly against the face plate, turbidity of the ambient seawater does not affect image quality. When the camera is raised, a wiper blade cleans off the face plate, the film is advanced by a motor drive, the strobe is recharged, and the camera can be lowered for another image.

2.4.2 REMOTS® Image Analysis

The REMOTS® images were analyzed with the full-color, SAIC Image Analysis System. This is a PC-based system integrated with a Javelin CCTV video camera and frame grabber. Color slides are digitally recorded as color images on computer disk. The image analysis software is a menu-driven program that incorporates user commands via keyboard and mouse. The system displays each color slide on the CRT while measurements of physical and biological parameters are obtained. Proprietary SAIC software allows the measurement and storage of data on up to 21 different variables for each REMOTS® image obtained. Automatic disk storage of all measured parameters allows data from any variables of interest to be compiled, sorted, displayed graphically, contoured, or compared statistically. All measurements were printed out on data sheets for a quality assurance check by an SAIC Senior Scientist before being approved for final data synthesis, statistical analyses, and interpretation. A summary of the major categories of REMOTS® data is presented below.

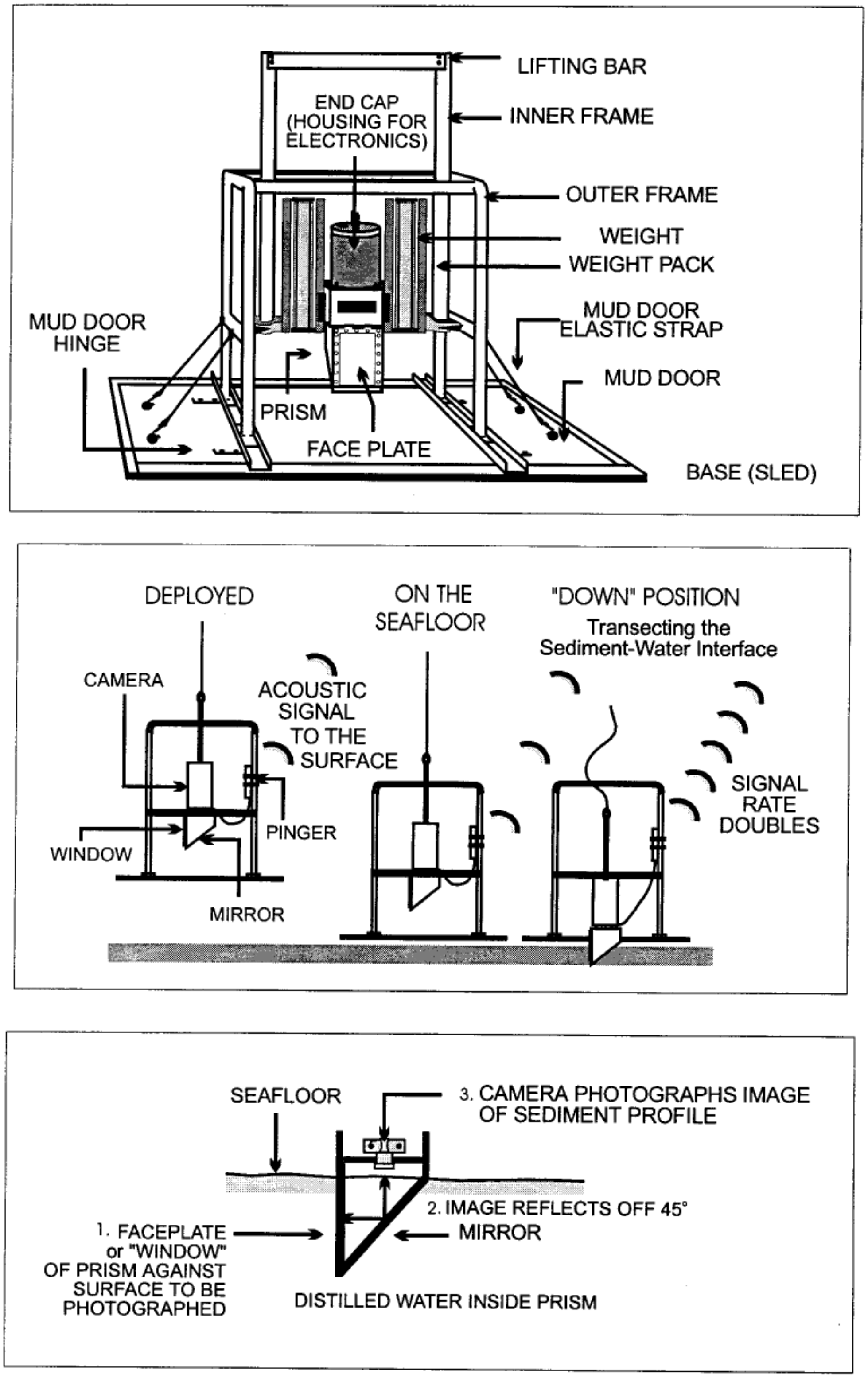


Figure 2-3. Schematic diagram of Benthos, Inc. Model 3731 REMOTS® sediment-profile camera and sequence of operation on deployment.

2.4.3 Sediment Type Determination

The sediment grain size major mode and range are estimated visually from the photographs by overlaying a grain size comparator which is at the same scale. This comparator was prepared by photographing a series of Udden-Wentworth size classes (equal to or less than coarse silt up to granule and larger sizes) through the REMOTS® camera. Seven grain size classes are on this comparator: >4 ϕ, 4 3 ϕ, 3 2 ϕ, 2 1 ϕ, 1 0 ϕ, 0-(-1 ϕ), and < 1 ϕ. The lower limit of optical resolution of the photographic system is about 62 microns (4 ϕ), allowing recognition of grain sizes equal to or greater than coarse silt. The accuracy of this method has been documented by comparing REMOTS® estimates with grain size statistics determined from laboratory sieve analyses.

The major modal grain size that is assigned to an image is the dominant grain size as estimated by area within the imaged sediment column. In those images that show layering of sand and mud, the dominant major mode assigned to a replicate therefore depends on how much area of the photograph is represented by sand versus mud. These textural assignments may or may not correspond to traditional sieve analyses depending on how closely the vertical sampling intervals are matched between the grab or core sample and the depth of the imaged sediment.

2.4.4 Boundary Roughness

Small-scale surface boundary roughness is measured from an image with the computer image analysis system. This vertical measurement is from the highest point at the sediment-water interface to the lowest point. This measurement of vertical relief is made within a horizontal distance of 15 cm (the total width of the optical window). Because the optical window is 20 cm high, the greatest possible roughness value is 20 cm. The source of the roughness is described if known. In most cases this is either biogenic (mounds and depressions formed by bioturbation or foraging activity) or relief formed by physical processes (ripples, scour depressions, rip-ups, mud clasts, etc.).

2.4.5 Optical Prism Penetration Depth

The optical prism penetrates the bottom under a static driving force imparted by the weight of the descending optical prism, camera housing, supporting mechanism, and weight packs. The penetration depth into the bottom depends on the force exerted by the optical prism and the bearing strength of the sediment. If the weight of the camera prism is held constant, the change in penetration depth over a surveyed site will reflect changes in geotechnical properties of the bottom. In this sense, the camera prism acts as a static-load penetrometer. The depth of penetration of the optical prism into the bottom can be a useful parameter, because dredged and capped materials often will have different shear strengths and bearing capacities.

2.4.6 Mud Clasts

When fine-grained, cohesive sediments are disturbed, either by physical bottom scour or faunal activity (e.g., decapod foraging), intact clumps of sediment are often scattered about the seafloor. These mud clasts can be seen at the sediment-water interface in REMOTS® images. During analysis, the number of clasts is counted, the diameter of a typical clast is measured, and their oxidation state is assessed. Depending on their place of origin and the depth of disturbance of the sediment column, mud clasts can be reduced or oxidized. Also, once at the sediment-water interface, these sediment clumps are subject to bottom-water oxygen levels and bottom currents. Based on laboratory microcosm observations of reduced sediments placed within an aerobic environment, oxidation of reduced surface layers by diffusion alone is quite rapid, occurring within 6 12 hours (Germano 1983). Consequently, the detection of reduced mud clasts in an obviously aerobic setting suggests a recent origin. The size and shape of mud clasts, e.g., angular versus rounded, are also considered. Mud clasts may be moved about and broken by bottom currents and/or animals (macro- or meiofauna; Germano 1983). Over time, large angular clasts become small and rounded. Overall, the abundance, distribution, oxidation state, and angularity of mud clasts are used to make inferences about the recent pattern of seafloor disturbance in an area.

2.4.7 Measurement of Dredged Material and Cap Layers

The recognition of dredged material from REMOTS® images is usually based on the presence of anomalous sedimentary materials within an area of ambient sediment. The ability to distinguish between ambient sediment and dredged or cap material demands that the survey extend well beyond the margins of a disposal site so that an accurate characterization of the ambient bottom is obtained. The distributional anomalies may be manifested in topographic roughness, differences in grain size, sorting, shell content, optical reflectance, fabric, or sediment compaction (i.e., camera prism penetration depth). Second-order anomalies may also provide information about the effects of dredged material on the benthos and benthic processes such as bioturbation (see following sections).

2.4.8 Apparent Redox Potential Discontinuity (RPD) Depth

Aerobic near-surface marine sediments typically have higher reflectance values relative to underlying anoxic sediments. Sand also has higher optical reflectance than mud. These differences in optical reflectance are readily apparent in REMOTS® images; the oxidized surface sediment contains particles coated with ferric hydroxide (an olive color when associated with particles), while reduced and muddy sediments below this oxygenated layer are darker, generally grey to black. The boundary between the colored ferric hydroxide surface sediment and underlying grey to black sediment is called the apparent redox potential discontinuity (RPD).

The depth of the apparent RPD in the sediment column is an important time-integrator of dissolved oxygen conditions within sediment pore waters. In the absence of bioturbating organisms, this high reflectance layer (in muds) will typically reach a thickness of 2 mm (Rhoads 1974). This depth is related to the supply rate of molecular oxygen by diffusion into the bottom and the consumption of that oxygen by the sediment and associated microflora. In sediments that have very high sediment-oxygen demand, the sediment may lack a high reflectance layer even when the overlying water column is aerobic.

In the presence of bioturbating macrofauna, the thickness of the high reflectance layer may be several centimeters. The relationship between the thickness of this high reflectance layer and the presence or absence of free molecular oxygen in the associated pore waters must be made with caution. The boundary (or horizon) which separates the positive Eh region (oxidized) from the underlying negative Eh region (reduced) can only be determined accurately with microelectrodes. For this reason, we describe the optical reflectance boundary, as imaged, as the “apparent” RPD, and it is mapped as a mean value.

The depression of the apparent RPD within the sediment is relatively slow in organic-rich muds (on the order of 200 to 300 micrometers per day); therefore, this parameter has a long time constant (Germano and Rhoads 1984). The rebound in the apparent RPD is also slow (Germano 1983). Measurable changes in the apparent RPD depth using the REMOTS® optical technique can be detected over periods of one or two months. This parameter is used effectively to document changes (or gradients) which develop over a seasonal or yearly cycle related to water temperature effects on bioturbation rates, seasonal hypoxia, sediment oxygen demand, and infaunal recruitment. In sediment-profile surveys of ocean disposal sites sampled seasonally or on an annual basis throughout the New England region performed under the DAMOS (Disposal Area Monitoring System) Program for the U.S. Army Corps of Engineers, New England Division, SAIC repeatedly has documented a drastic reduction in apparent RPD depths at disposal sites immediately after dredged material disposal, followed by a progressive postdisposal apparent RPD deepening (barring further physical disturbance). Consequently, time-series RPD measurements can be a critical diagnostic element in monitoring the degree of recolonization in an area by the ambient benthos.

The depth of the mean apparent RPD also can be affected by local erosion. The peaks of disposal mounds commonly are scoured by divergent flow over the mound. This can result in washing away of fines, development of shell or gravel lag deposits, and very thin apparent RPD depths. During storm periods, erosion may completely remove any evidence of the apparent RPD (Fredette et al. 1988).

Another important characteristic of the apparent RPD is the contrast in reflectance values at this boundary. This contrast is related to the interactions among the degree of organic-loading, bioturbational activity in the sediment, and the levels of bottom-water dissolved oxygen in an area. High inputs of labile organic material increase sediment oxygen demand and, subsequently, sulfate reduction rates (and the abundance of sulfide end-products). This results in more highly reduced (lower reflectance) sediments at depth and higher RPD contrasts. In a region of generally low RPD contrasts, images with high RPD contrasts indicate localized sites of relatively high past inputs of organic-rich material (e.g., organic or phytoplankton detritus, dredged material, sewage sludge, etc.).

2.4.9 Sedimentary Methane

At extreme levels of organic-loading, pore-water sulphate is depleted, and methanogenesis occurs. The process of methanogenesis is detected by the appearance of methane bubbles in the sediment column. These gas-filled voids are readily discernible in REMOTS® images because of their irregular, generally circular aspect and glassy texture (due to the reflection of the strobe off the gas). If present, the number and total areal coverage of all methane pockets are measured.

2.4.10 Infaunal Successional Stages

The mapping of successional stages, as employed in this project, is based on the theory that organism-sediment interactions in fine-grained sediments follow a predictable sequence after a major seafloor perturbation (e.g., passage of a storm, disturbance by bottom trawlers, dredged material deposition, hypoxia). This theory states that primary succession results in "the predictable appearance of macrobenthic invertebrates belonging to specific functional types following a benthic disturbance. These invertebrates interact with sediment in specific ways. Because functional types are the biological units of interest, our definition does not demand a sequential appearance of particular invertebrate species or genera" (Rhoads and Boyer 1982). This theory is formally developed in Rhoads and Germano (1982; 1986) and Rhoads and Boyer (1982).

The term disturbance is used here to define natural processes, such as seafloor erosion, changes in seafloor chemistry, and foraging disturbances which cause major reorganization of the resident benthos; disturbance also includes anthropogenic impacts, such as dredged material or sewage sludge disposal, thermal effluent from power plants, bottom trawling, pollution impacts from industrial discharge, etc. An important aspect of using this successional approach to interpret benthic monitoring results is relating organism-sediment relationships to the dynamical aspects of end-member successional stages (i.e., Stage I, II, or III communities as defined in the following paragraphs). This involves deducing dynamics from structure, a technique pioneered by R. G. Johnson (1972) for marine soft-bottom habitats. The application of this approach to benthic monitoring requires *in situ* measurements of salient structural features of organism-sediment relationships as imaged through REMOTS® technology.

Pioneering assemblages (Stage I assemblages) usually consist of dense aggregations of near-surface living, tube-dwelling polychaetes; alternately, opportunistic bivalves may colonize in dense aggregations after a disturbance (Rhoads and Germano 1982, Santos and Simon 1980a). These functional types are usually associated with a shallow redox boundary; bioturbation depths are shallow, particularly in the earliest stages of colonization. In the absence of further disturbance, these early successional assemblages are eventually replaced by infaunal deposit feeders; the start of this "infaunalization" process is designated arbitrarily as Stage II. Typical Stage II species are shallow dwelling bivalves or, as is common in New England waters, tubicolous amphipods. In studies of hypoxia-induced benthic defaunation events in Tampa Bay, Florida, ampeliscid amphipods appeared as the second temporal dominant in two of the four recolonization cycles (Santos and Simon 1980a, 1980b).

Stage III taxa, in turn, represent high-order successional stages typically found in low-disturbance regimes. These invertebrates are infaunal, and many feed at depth in a head-down orientation. The localized feeding activity results in distinctive excavations called feeding voids. Diagnostic features of these feeding structures include a generally semicircular shape with a flat bottom and arched roof, and a distinct granulometric change in the sediment particles overlying the floor of the structure. This granulometric change is caused by the accumulation of coarse particles that are rejected by the animals feeding selectively on fine-grained material. Other subsurface structures, such as burrows or methane gas bubbles, do not exhibit these characteristics and therefore are quite distinguishable from these distinctive feeding structures. The bioturbational activities of these deposit-feeders are responsible for aerating the sediment and causing the redox horizon to be located several centimeters below the sediment-water interface. In the retrograde transition of Stage III to Stage I, it is sometimes possible to recognize the presence of relic (i.e., collapsed and inactive) feeding voids.

The end-member stages (Stages I and III) are easily recognized in REMOTS® images by the presence of dense assemblages of near-surface polychaetes and the presence of subsurface feeding voids, respectively; both types of assemblages may be present in the same image. Additional information on REMOTS® image interpretation can be found in Rhoads and Germano (1982, 1986).

2.4.11 Organism-Sediment Index (OSI)

The multi-parameter REMOTS® Organism-Sediment Index (OSI) has been constructed to characterize habitat quality. Habitat quality is defined relative to two end-member standards. The lowest value is given to those bottoms which have low or no dissolved oxygen in the overlying bottom water, no apparent macrofaunal life, and methane gas present in the sediment (see Rhoads and Germano 1982, 1986, for REMOTS® criteria for these conditions). The OSI for such a condition is -10. At the other end of the scale, an aerobic bottom with a deeply depressed RPD, evidence of a mature macrofaunal assemblage, and no apparent methane gas bubbles at depth will have an OSI value of +11.

The OSI is a sum of the subset indices shown in Table 2-1. The OSI is calculated automatically by SAIC software after completion of all measurements from each REMOTS® photographic negative. The index has proven to be an excellent parameter for mapping disturbance gradients in an area and documenting ecosystem recovery after disturbance (Germano and Rhoads 1984, Revelas et al. 1987, Valente et al. 1992).

The OSI may be subject to seasonal changes because the mean apparent RPD depths vary as a result of temperature-controlled changes of bioturbation rates and sediment oxygen demand. Furthermore, the successional status of a station may change over the course of a season related to recruitment and mortality patterns or the disturbance history of the bottom. The sub-annual change in successional status is generally limited to Stage I (Polychaete-dominated) and Stage II (amphipod-dominated) seres. Stage III seres tend to be maintained over periods of several years unless they are eliminated by increasing organic loading, extended periods of hypoxia, or burial by thick layers of dredged material. The recovery of Stage III seres following abatement of such events may take several years (Rhoads and Germano 1982). Stations that have low OSI values (+6) are indicative of recently disturbed areas and tend to have greater temporal and spatial variation in benthic habitat quality than stations with higher OSI values (> +8).

Table 2-1

Calculation of REMOTS® Organism Sediment Index Value

A. CHOOSE ONE VALUE:		
	Mean RPD Depth	Index Value
	0.00 cm	0
	> 0 - 0.75 cm	1
	0.75 - 1.50 cm	2
	1.51 - 2.25 cm	3
	2.26 - 3.00 cm	4
	3.01 - 3.75 cm	5
	> 3.75 cm	6
B. CHOOSE ONE VALUE:		
	Successional Stage	Index Value
	Azoic	-4
	Stage I	1
	Stage I ® II	2
	Stage II	3
	Stage II ® III	4
	Stage III	5
	Stage I on III	5
	Stage II on III	5
C. CHOOSE ONE OR BOTH IF APPROPRIATE:		
	Chemical Parameters	Index Value
	Methane Present	-2
	No/Low Dissolved Oxygen**	-4
REMOTS® ORGANISM-SEDIMENT INDEX =	Total of above subset indices (A+B+C)	
	RANGE: -10 - +11	

** Note: This is not based on a Winkler or polarigraphic electrode measurement. It is based on the imaged evidence of reduced, low reflectance (i.e., high oxygen demand) sediment at the sediment-water interface.

3.0 RESULTS

A total of 674 REMOTS® sediment-profile images were obtained at the 158 project area stations and 50 reference stations; 422 of these images were analyzed for this report. One of the multiple planview images obtained at each station also was analyzed for this report, except for 20 stations where planview images were not obtained due to a camera malfunction. The results of the REMOTS® and planview image analyses are presented below in two main sections: the characterization of remediation cells 1, 2 and 3 (Section 3.1), and the characterization of the candidate reference areas (Section 3.2).

3.1 Characterization of HARS Remediation Cells 1, 2 and 3

3.1.1 Planview Photograph Analysis

Analysis of the planview images indicated that surface sediments within HARS remediation cells 1, 2 and 3 were either silt/clay (48% of stations), sand (16% of stations), or a mixture of cobbles and pebbles over sand or silt (23% of stations). Twenty stations, representing 8% of the total, lacked planview images due to a camera malfunction
(Figure 3-1). The greatest concentration of stations having sand occurred on the eastern side of remediation cells 1 and 2 (Figure 3-1). The sand was rippled at most of these stations (Figures 3-1 and 3-2). This is an area in which the bottom slopes downward moving from east to west. The peaks of two historic disposal mounds occur at a depth of roughly 15 m, and depths increase steadily moving down the sandy slope until an elongated topographic depression ("basin"), roughly defined by the 23 to 24 m depth contours, is encountered (Figure 3-1). This elongated basin is the dominant topographic feature in remediation cells 1, 2 and 3.

At stations within the elongated basin, the planview images indicated that silt-clay was the dominant sediment type (Figure 3-1). While a significant number of stations in remediation cell 1 within the basin lacked images, it is speculated from both the REMOTS® analysis and the surrounding planview results that these stations would have been designated silt-clay in Figure 3-1. Cobbles and/or pebbles were observed at the sediment surface at stations throughout the area, particularly those on the sloped sides of the elongated basin above the 24 m depth contour (Figures 3-1 and 3-3).

Various types of epifaunal organisms and worm tubes were observed in the planview images at stations throughout the surveyed area (Figure 3-4). Worm tubes were more common, occurring at both silt-clay and sandy stations (e.g., Figure 3-2). Mobile epifauna included crustaceans (e.g., crabs and lobsters), sea stars, and sand dollars (Figures 3-3 and 3-5). Where larger rocks were encountered, they were typically covered with encrusting epifauna (e.g., hydroids and bryozoans), along with mobile foragers like sea stars. Bottom and pelagic fish, such as squid, flounder, and skate, were seen in the planview images at several stations throughout the area.

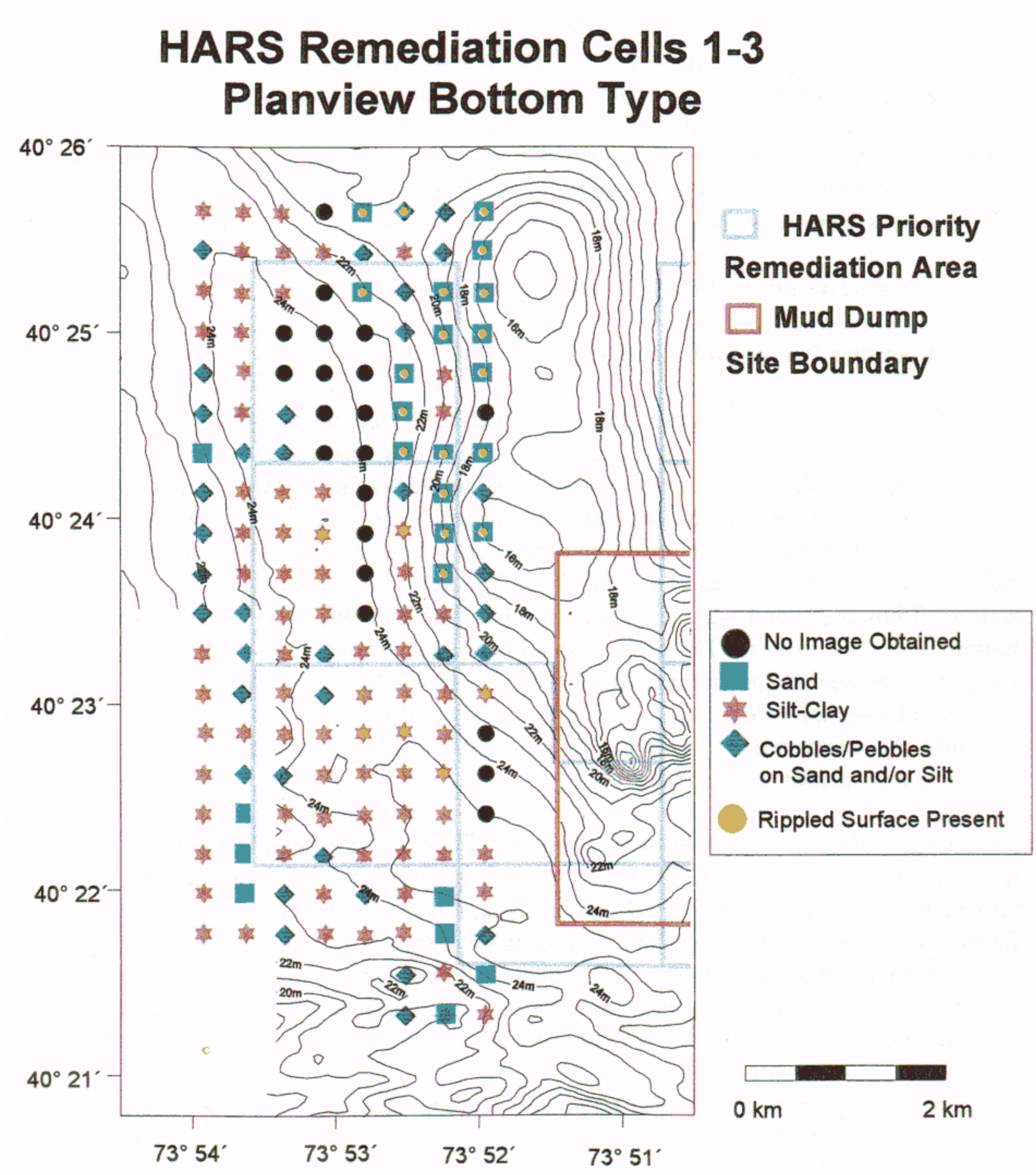


Figure 3-1. Map showing bottom types in HARS remediation cells 1–3 based on analysis of sediment planview photographs.

Figure 3-2. Planview image of station I-2800 showing the rippled sand which characterized the sloping bottom found on the eastern side of remediation cells 1 and 2. A few polychaete tubes can be seen among the sand ripples.

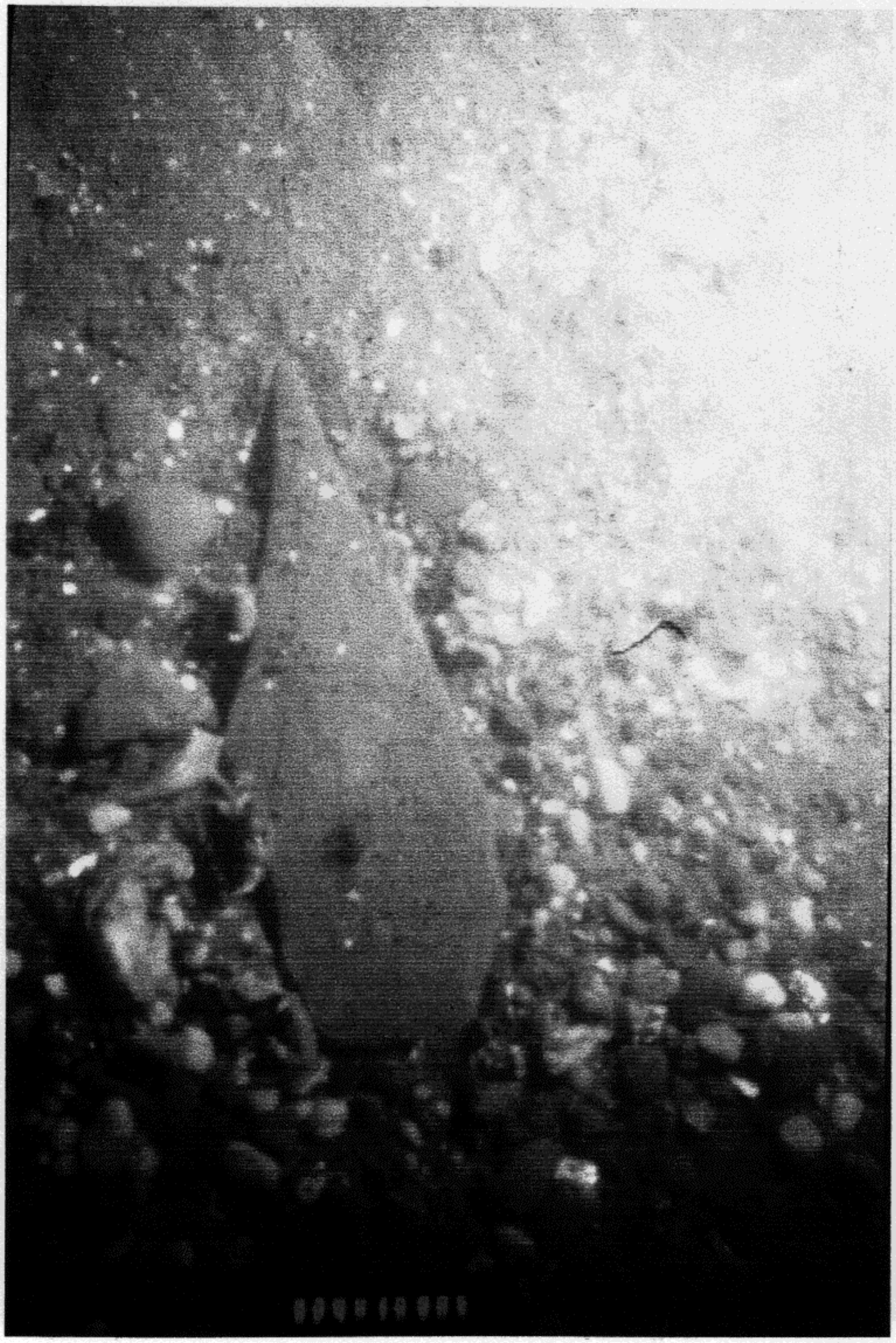


Figure 3-3. Planview image of station E-0 showing a mixture of cobbles and pebbles on the sand surface. Two small crabs are visible next to the large cobble at center.

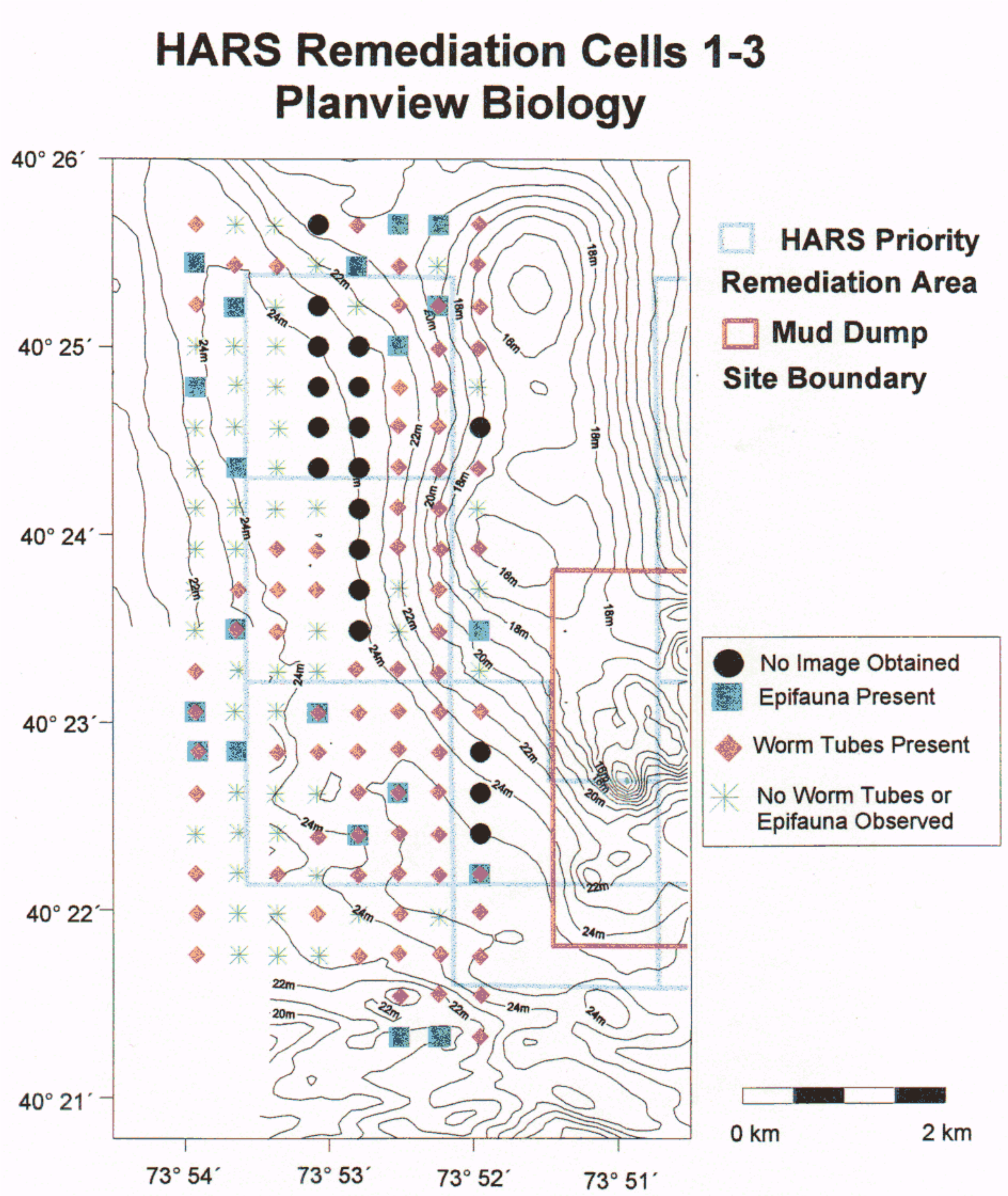


Figure 3-4. Map showing stations where epifauna and/or worm tubes were observed in planview images.

Figure 3-5. Planview image of station U-2400 showing a juvenile lobster burrowing under a large rock.

3.1.2 REMOTS® Image Analysis

Horizontal Distribution of Sediment Grain Size

Analysis of the REMOTS® images indicated a variety of sediment types were present within the surveyed area at HARS. However, while the particle size of surface sediments in the area ranged from gravel (<-1 phi) to silt-clay (>4 phi), very fine sand (4 to 3 phi) and silt-clay (>4 phi) were the dominant grain size major modes (Figure 3-6).

In general, the silt-clay (>4 phi) was found primarily within the elongated basin which dominates remediation cells 1, 2 and 3, while the sands were found on the sloping bottom representing the sides of this basin (Figure 3-7). On the sloping bottom comprising the eastern and northern sides of the basin, very fine sand (4 to 3 phi) and fine sand (3 to 2 phi) were dominant (Figure 3-7). Most of these sands were rippled, suggesting a slightly higher energy level associated with the shallower depths (Figure 3-8a). A group of stations on the western sloped side of the basin, just outside remediation cell 2, had medium to coarse sands in the 1 to 0 phi and 2 to 1 phi size ranges (Figures 3-7 and 3-8b). Many of the stations south of the basin, within and around remediation cell 3, had fine sand (3 to 2 phi).

Scattered throughout the surveyed area were stations having rocks of various sizes (e.g., boulders, cobbles, pebbles having a major mode of <-1 phi). Many of the stations in the northeast corner of the sampling grid had both rocks and sand present in the replicate REMOTS® images; these stations were mapped with a "variable" grain size in Figure 3-6. Overall, the horizontal distribution of different sediment types in the surveyed area was related closely to water depth. Silt-clay and silty, very fine sands filled the basin below the 23 m depth contour, while fine to medium sands occurred on the shallower sloping sides of the basin between the 16 and 23 m contours.

Dredged Material Distribution

Dredged material is recognized in REMOTS® images by the presence of low optical reflectance (i.e., dark-colored) silt-clay sediments with chaotic fabrics or layered stratigraphy. Two distinguishable types of dredge material were observed in the REMOTS® images obtained in this survey. The first and most prevalent was relic dredge material, which was found uniformly throughout the basin inside the 24 m depth contour and in patches on the eastern sloped side of the basin between the 24 and 20 m depth contours (Figure 3-9). The distribution of dredged material in Figure 3-9 closely matches the distribution of fine-grained sediment shown in Figure 3-7. This is not surprising, since one of the distinguishing features of the dredged material was its fine-grained texture. The material was further distinguished by its very dark color (e.g., dark gray or black) below a shallow redox layer (Figure 3-10a). At most stations, the dredge material was observed in the profile image extending from the sediment surface to below the penetration depth of the REMOTS® camera prism (i.e., the thickness of the dredge material

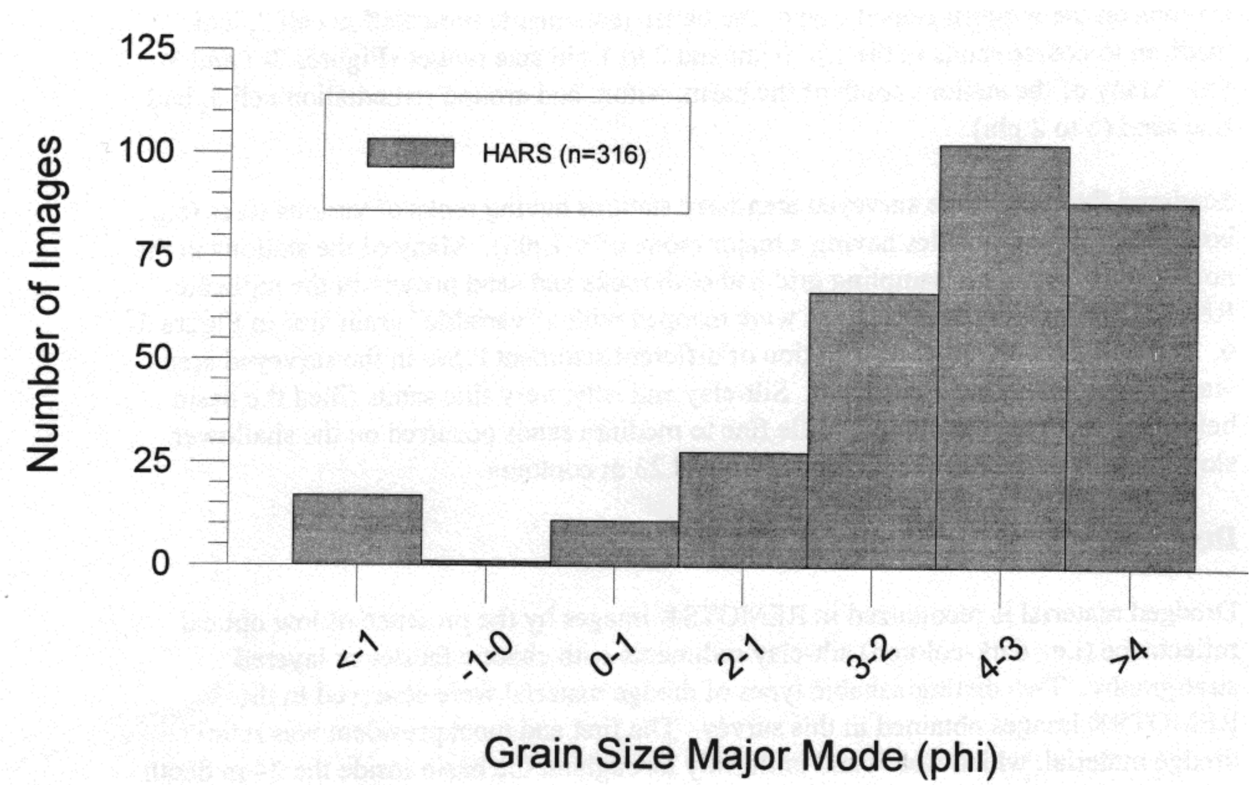


Figure 3-6. Frequency distribution of grain size major mode for all replicate REMOTS® images obtained in and around HARS remediation cells 1, 2, and 3.

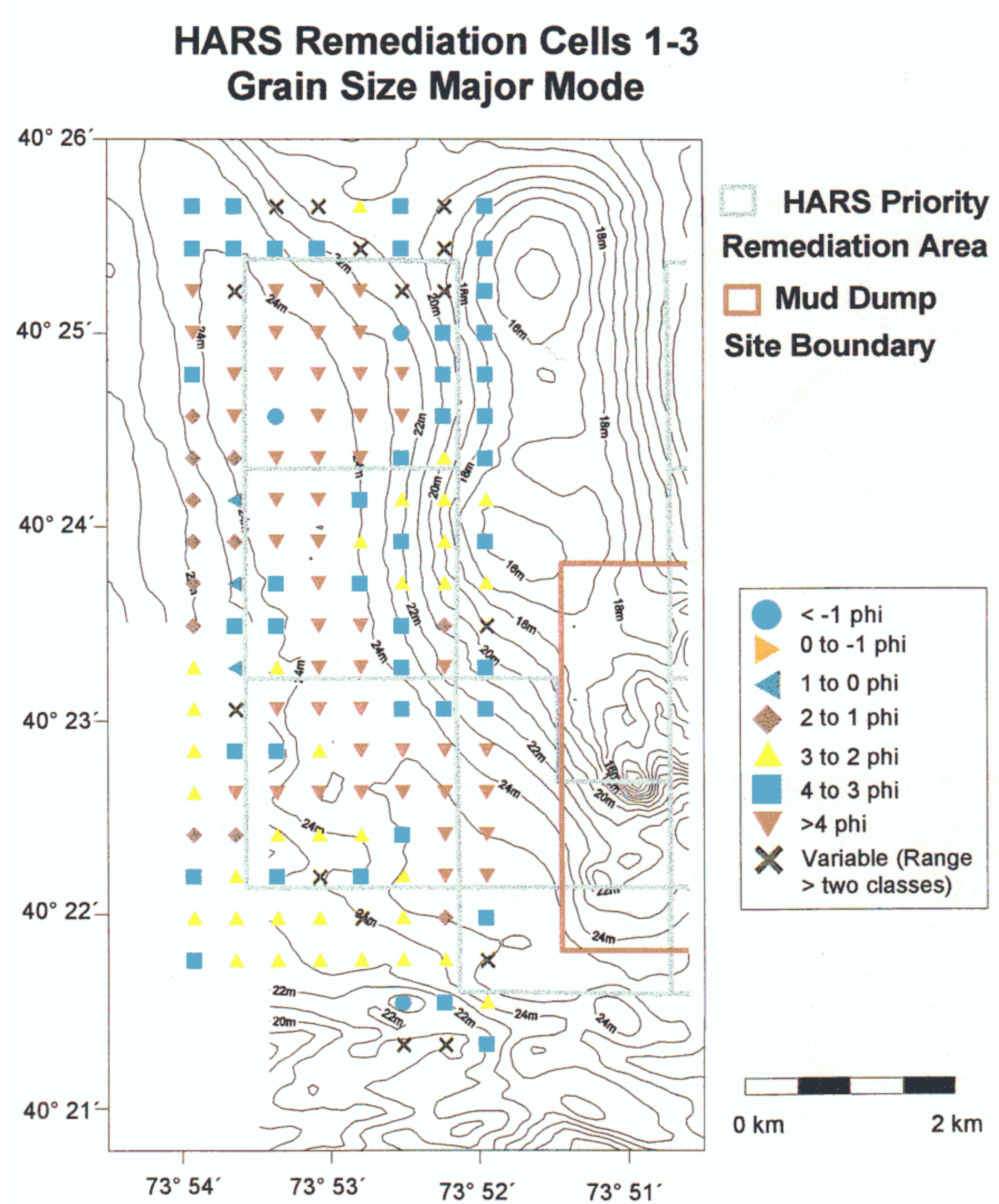
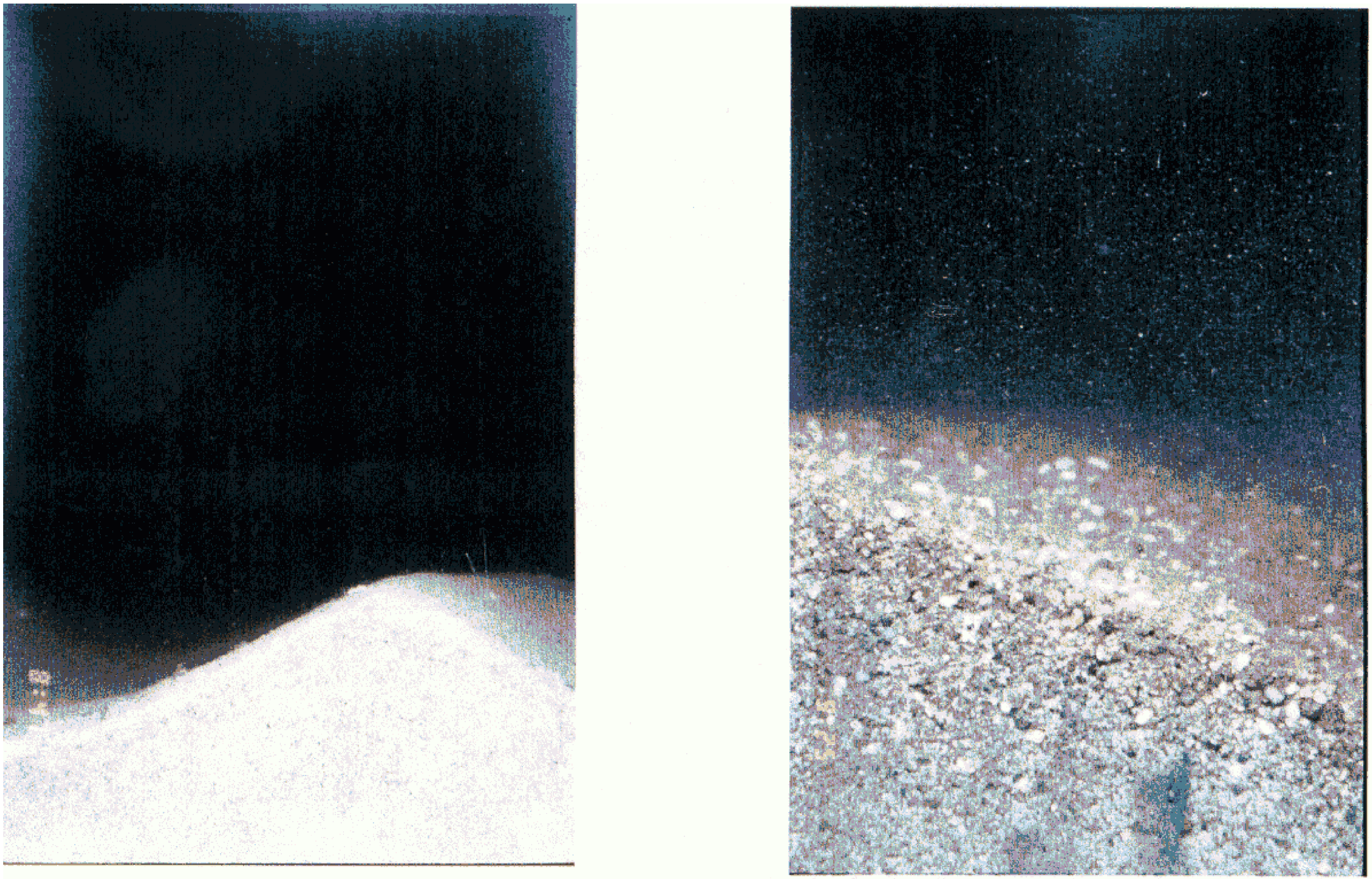


Figure 3-7. Map of grain size major mode at each station in the HARS survey area based on REMOTS® analysis.



A B

Figure 3-8. Two REMOTS images showing sandy sediments in the surveyed area. Image A from HARS station B-2800 shows the rippled, very fine sand (4 to 3 phi) which characterized the sloping bottom to the east of the elongated basin. Image B from station G-0 shows medium sand (2 to 1 phi) which was found on the western sloped side of the basin.

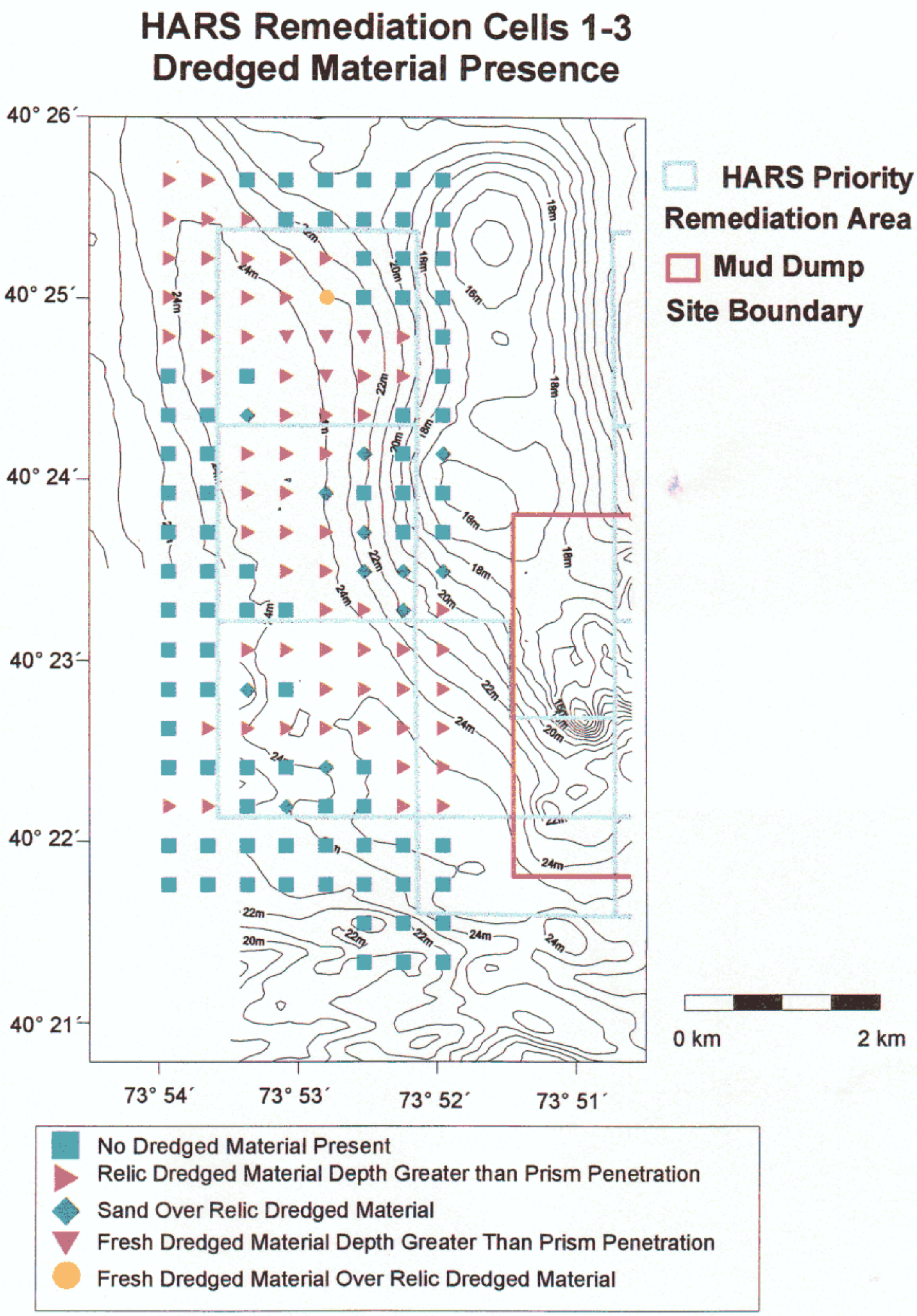


Figure 3-9. Map showing the presence of relic and fresh dredged material within the HARS survey area.

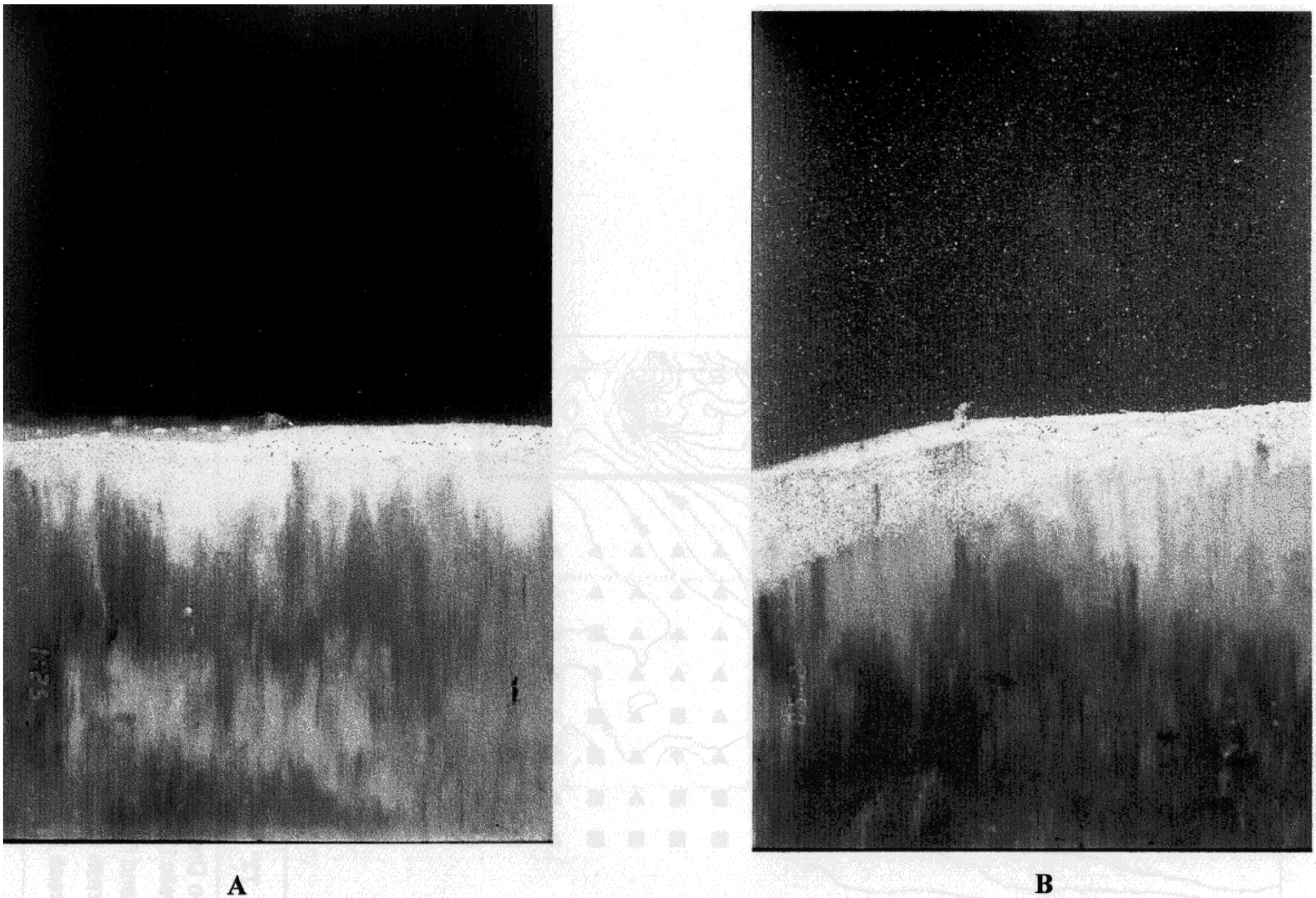


Figure 3-10. Two representative REMOTS images illustrating the relic dredged material observed at a large number of stations within the elongated basin. In image A from station G-1200, the black, relic dredged material has a shallow redox layer and extends from the sediment surface to below the camera's imaging depth. Image B from station L-2400 shows a thin surface layer of sand over black relic

layer exceeded the prism penetration depth). At a number of stations in remediation cell 2, on the sloped eastern side of basin, the black relic dredged material was covered by a surface layer of sand (Figure 3-10b).

The second type of dredge material was characterized by a light grey color and soft texture that helped make it clearly distinguishable from the black relic dredged material (Figure 3-11). This “fresh” material was observed only in remediation cell 1, at stations E-1200, D-1600, E-1600, F-1600 and E-2000 (Figure 3-9). It was designated as fresh because this material was disposed as part of the Passenger Ship Terminal dredging project which occurred in March and April of 1998. The five stations where this material was observed all occur within the circular target area used for placement of this material within HARS remediation cell 1.

Small-Scale Surface Boundary Roughness

Measurements of boundary roughness are limited by the window size of the REMOTS® camera (15 × 20 cm). When small-scale surface features predominate (e.g., sand ripples with amplitudes less than the width of the camera window), the camera can provide an accurate measure of boundary roughness. However, the camera cannot provide an accurate measurement of boundary roughness when large-scale features predominate (e.g., sand ripples with amplitudes exceeding the width of the REMOTS® camera window). Therefore, it is important to note that the REMOTS® measurements are of small-scale boundary roughness only.

Figure 3-12 shows the spatial distribution of small-scale boundary roughness in the project area; the mapped values are averages for the replicate images obtained at each station. From this figure, it can be seen that approximately 90% of the boundary roughness values were less than 2 cm. This is further illustrated in the frequency distribution of boundary roughness values for all replicate images (Figure 3-13). The majority of boundary roughness values measured in the images obtained in the survey area were in the 0.5-1.0 cm range. Three of the six stations which showed a boundary roughness between 3 and 5 cm were located on the eastern side of the station grid, in shallower water, and on steeper sloped bottom conditions as signified by the closely spaced contour lines. These stations all had sand and probably experience higher energy conditions due to the shallower water. The other three stations having relatively high boundary roughness were located on the western side of the station grid and were characterized by coarser sand.

Camera Prism Penetration Depth

The depth of penetration of the REMOTS® camera prism can be used to map gradients in the bearing strength (hardness) of the sediment. This hardness parameter is useful for distinguishing between a relatively thick (>20 cm) layer of sand cap material or soft bottom related to the presence of thin caps or underlying silt/clay. Freshly deposited sediments or older, highly bioturbated sediments tend to be soft, while compacted sands

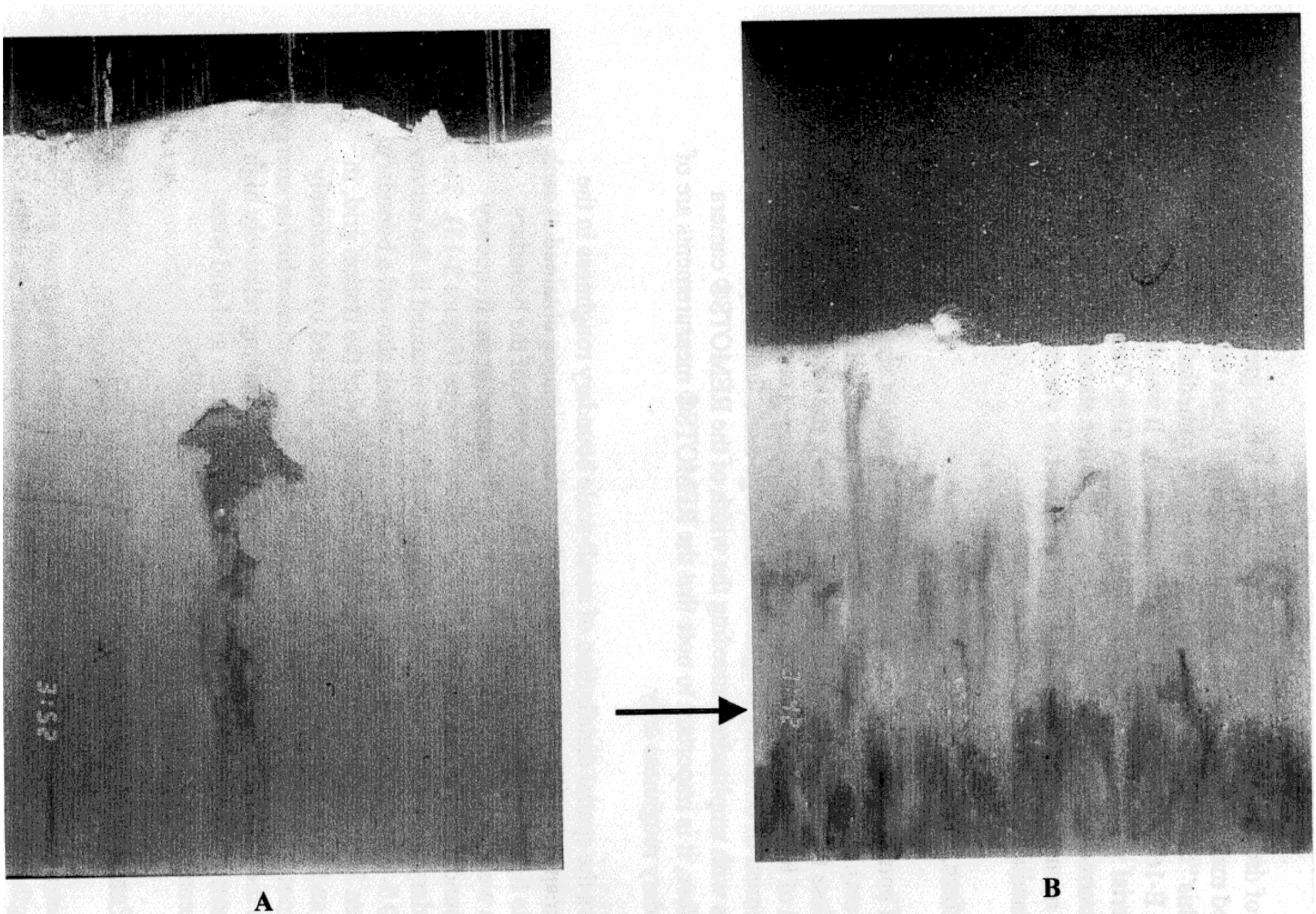


Figure 3-11. Two REMOTS images showing the "fresh" dredged material found at five stations in HARS remediation cell 1. Image A from station E-1600 shows the uniformly grey-colored material extending from the sediment surface to below the camera's imaging depth. Note the deeper camera penetration in this material compared to the relic dredged material shown in Figure 3-10. Image B from station D-1600 shows a surface layer of the fresh grey material overlying black, relic dredged material. An arrow marks the point of contact between the two layers.

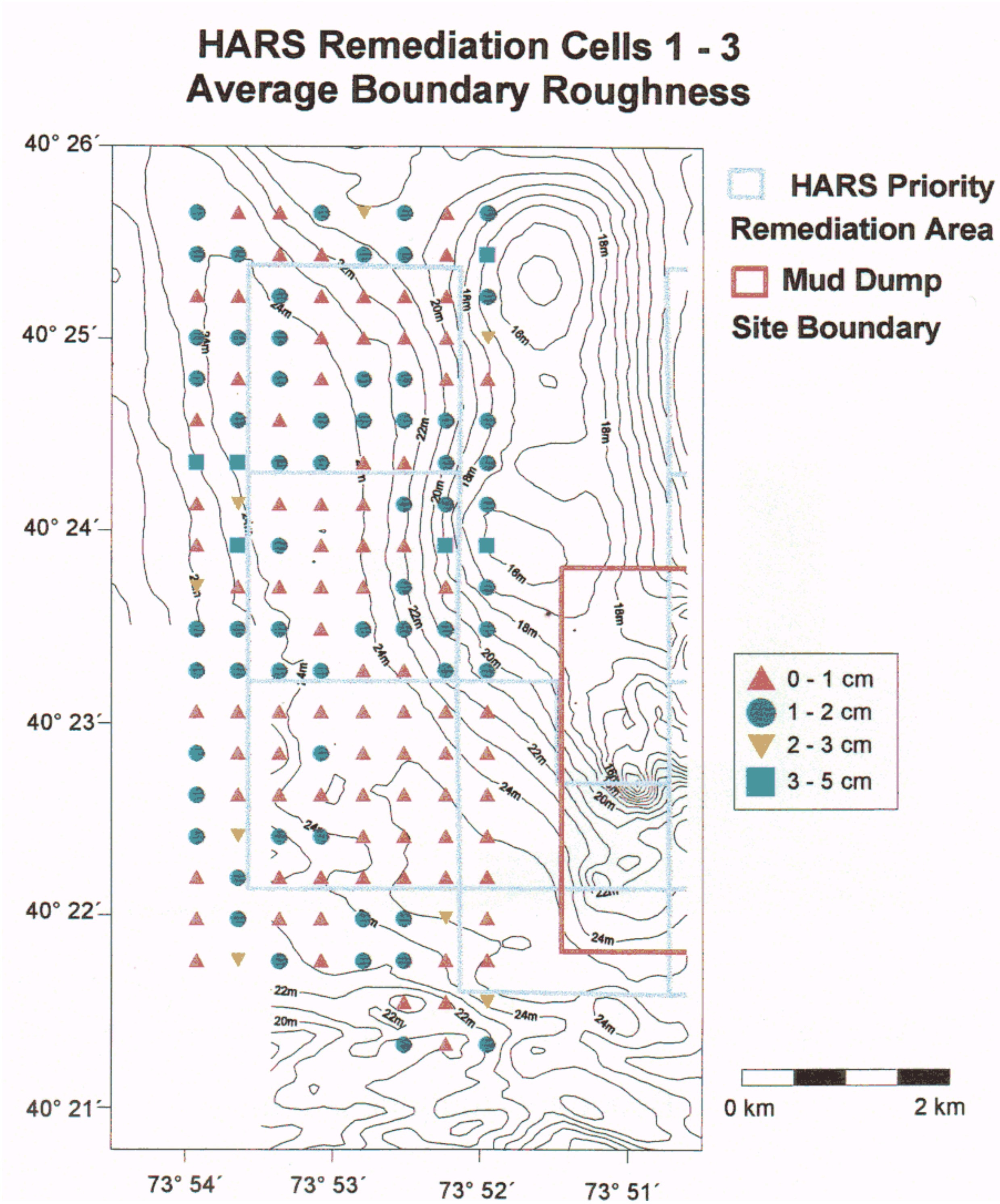


Figure 3-12. Map of average small-scale boundary roughness values at the sampled stations.

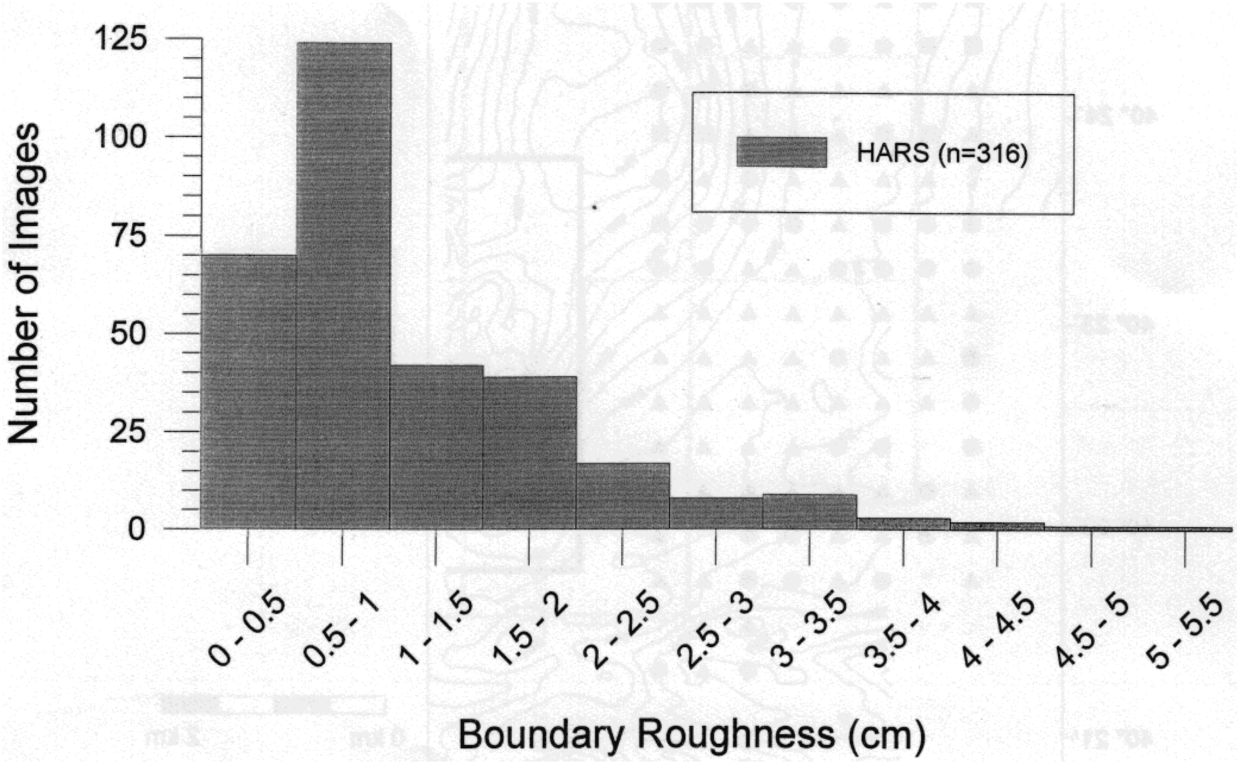


Figure 3-13. Frequency distribution of small-scale boundary roughness values for all replicate REMOTS® images obtained in HARS remediation cells 1, 2 and 3.

are hard and resist camera prism penetration. During the August 1998 survey, weight was added to or removed from the REMOTS® camera frame to optimize penetration in the diverse types of sediment encountered across the surveyed areas. Therefore, it is not possible to use camera prism penetration depth as a direct comparative measure of sediment bearing strength or density among different stations. Nevertheless, some broad qualitative comparisons of average prism penetration among stations are possible. As might be expected, the deepest prism penetration (in the range of 10 to 20 cm) was found at the stations having "fresh" dredge material resulting from the March/April 1998 Passenger Ship Terminal dredging project, centered around station E-1600 in remediation cell 1 (Figure 3-14). Intermediate penetration values (5 to 10 cm) generally were found at stations having relic dredged material within the basin, while the shallowest penetration was at the sandy and rocky stations located on the sloping sides of the basin (Figure 3-14).

Infaunal Successional Stage

At many stations where sand, pebbles or rocks were the dominant sediment type, the penetration of the REMOTS® camera prism was hindered and the infaunal successional stage paradigm could not be applied. An "indeterminate" successional stage designation was applied to roughly 16% (25 stations) of the replicate images obtained in the August 1998 survey. Nearly half of the indeterminate classifications appeared at the western- and southeastern-most edges of the rectangular station grid (Figure 3-15).

Stage I was the dominant successional stage found in the surveyed area at HARS, occurring at 116 of the 158 stations (73%), while Stage I on III was found at only 16 (10%) of the stations (Figure 3-15). The evidence of Stage I consisted primarily of polychaete tubes occurring at the sediment surface (Figure 3-16a). The surface tubes were found both at sandy and silt-clay stations. Burrowing anemones, most likely the species *Ceriantheopsis americanus*, were observed both at the sediment surface and at depth within the sediment at a limited number of stations (Figures 3-15 and 3-16b). At a significant number of stations, dead shells or shell hash were present at the sediment surface (Figure 3-15). In some instances, the dead shell layer was dense and appeared to consist largely of the bivalve *Nucula proxima*, a species which is common throughout the New York Bight region (Figure 3-16c).

Apparent RPD Depth

Sands generally are characterized by low concentrations of ferrous hydroxides and organic material and therefore tend to lack an obvious color contrast to mark the division between aerobic and anaerobic zones in the sediment column. The lack of color contrast makes it difficult to measure the depth of the apparent RPD in REMOTS® images of sand. However, it is assumed that rippled sands in the New York Bight generally are well aerated as a result of both diffusion of oxygen from the overlying water and physical mixing associated with periodic bedload transport. Therefore, in REMOTS® images of

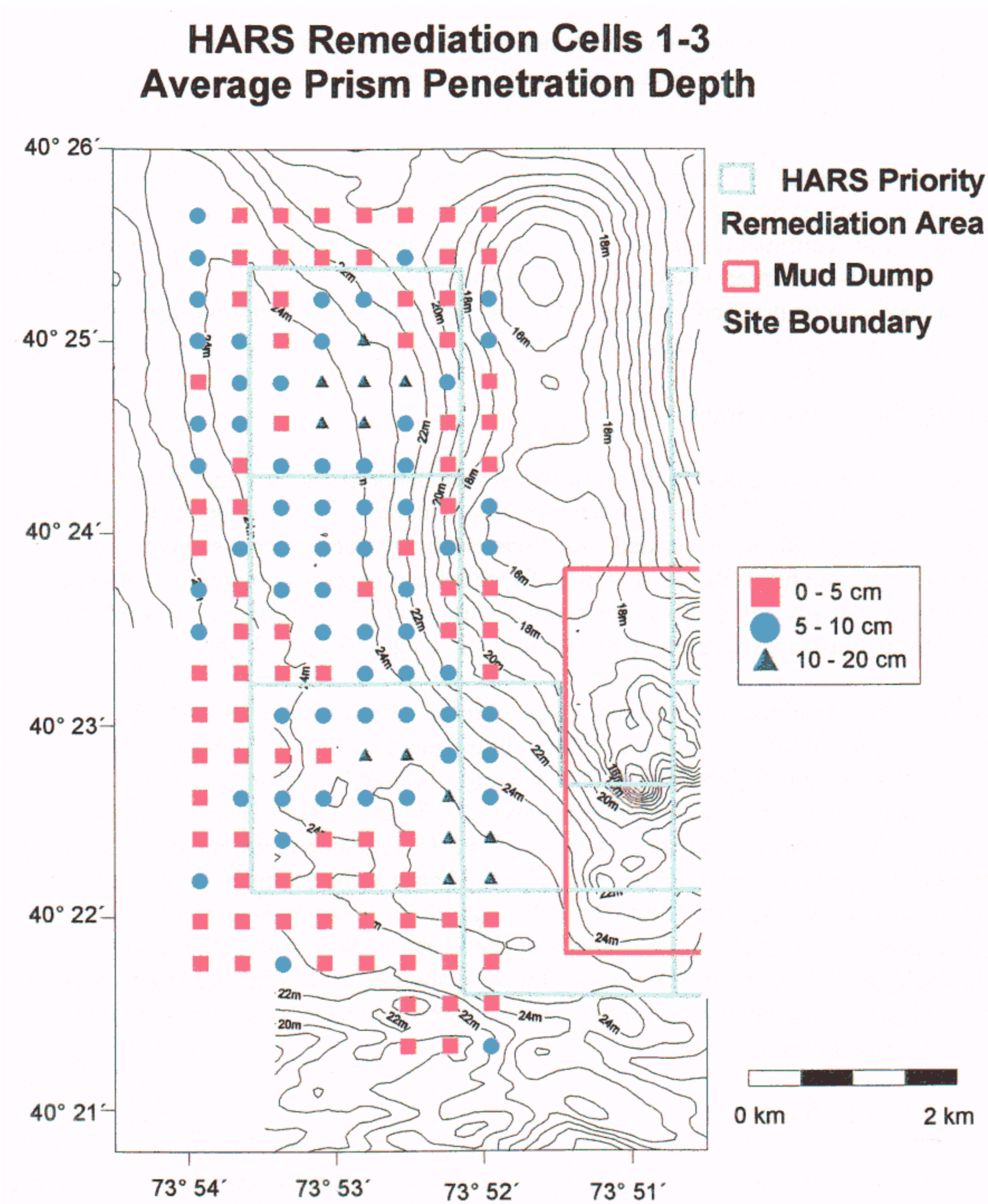


Figure 3-14. Map of average prism penetration depths in the HARS survey area.

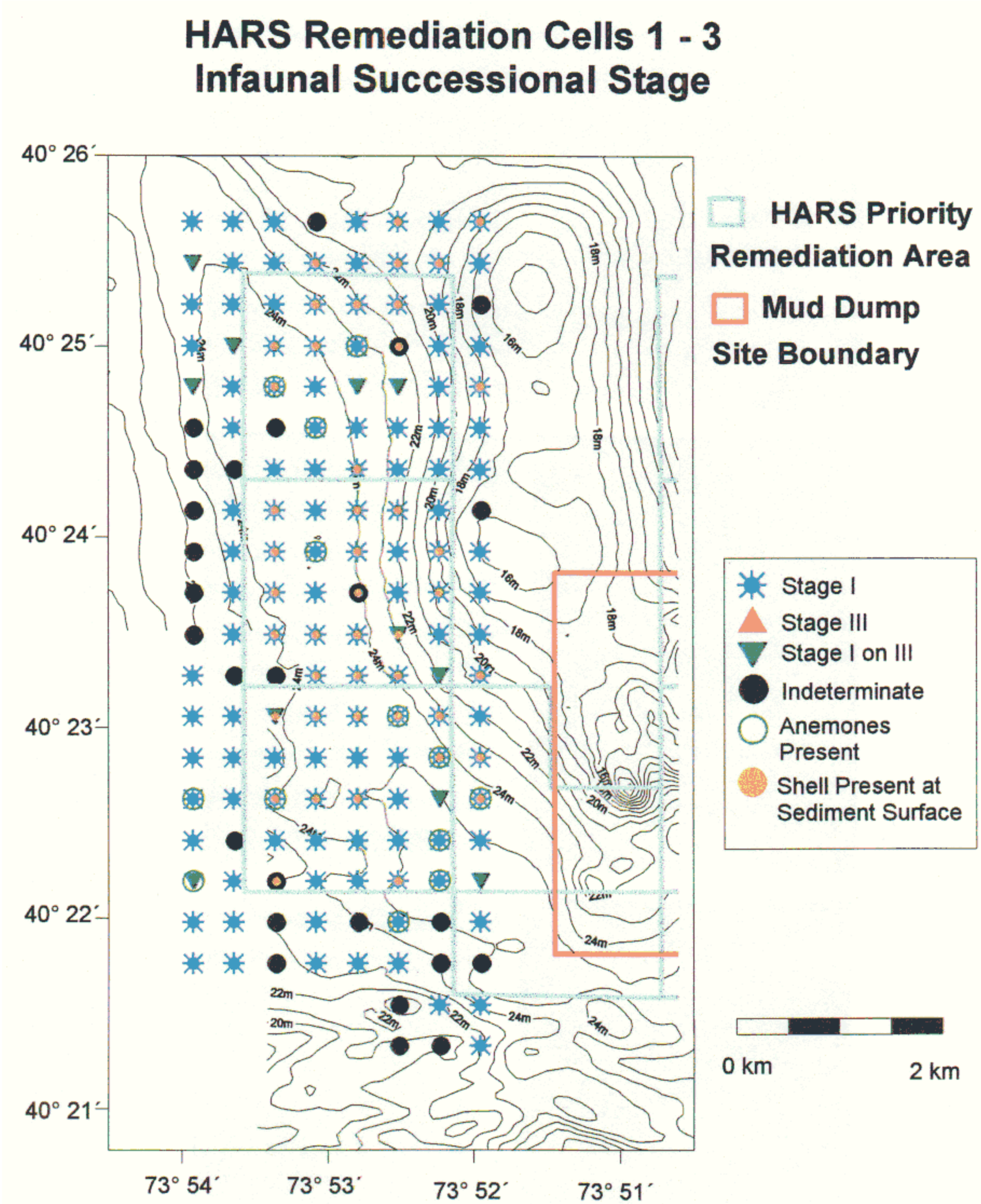


Figure 3-15. Infaunal successional stages in and around HARS remediation cells 1, 2, and 3 as determined from REMOTS®. The highest order successional stage for the replicate images obtained at each station has been mapped.

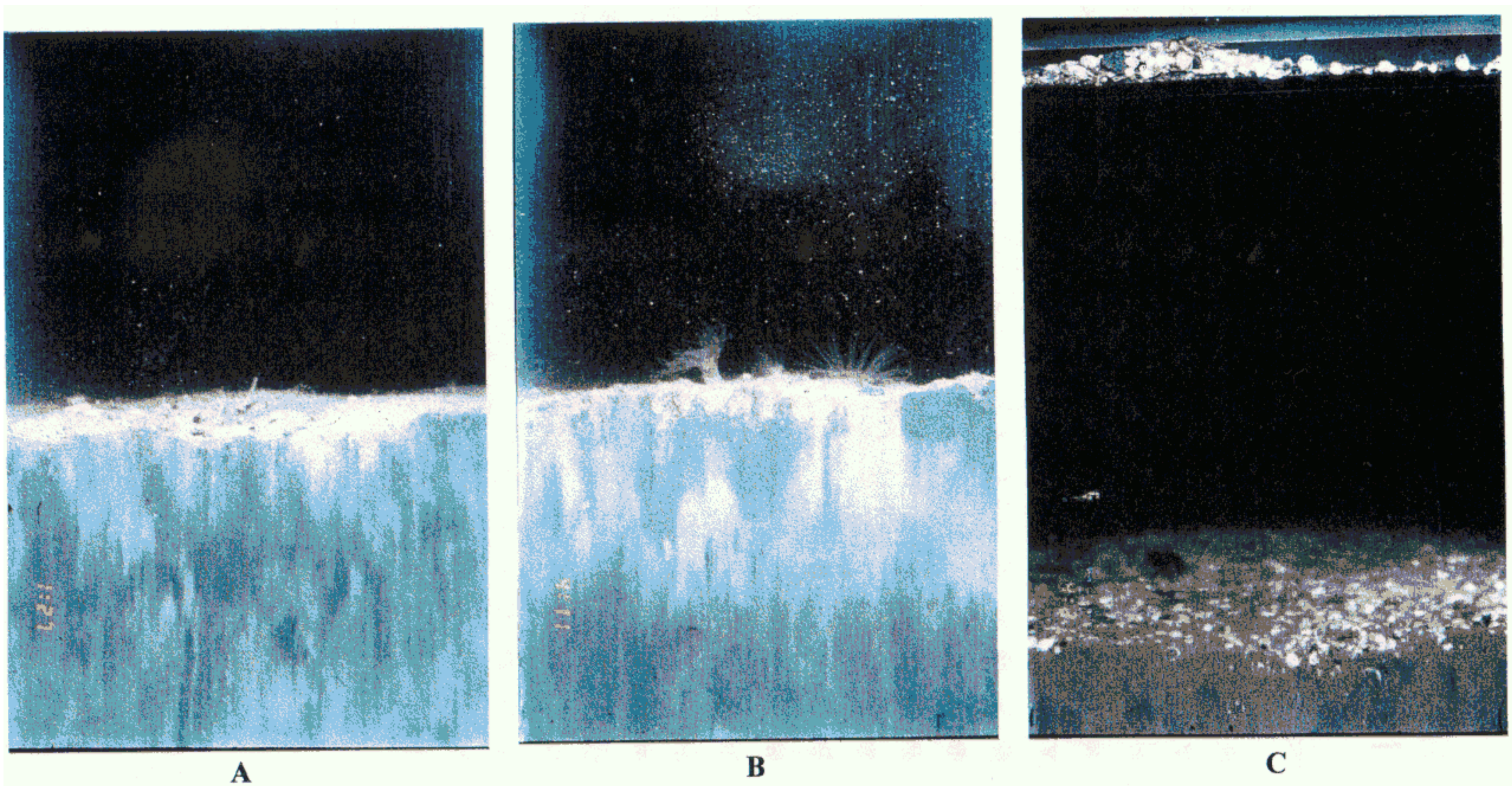


Figure 3-16. Three REMOTS images illustrating different biological features. Image A from station G-1200 within the basin shows several Stage I polychaete tubes at the sediment surface; the sediment consists of relic dredged material with a very shallow redox layer (similar to Figure 3-10a). Image B from station Q-2400 shows burrowing anemones at the surface of relic dredged material. Image C shows a dense surface layer of dead shells, possibly of the bivalve *Nucula proxima*.

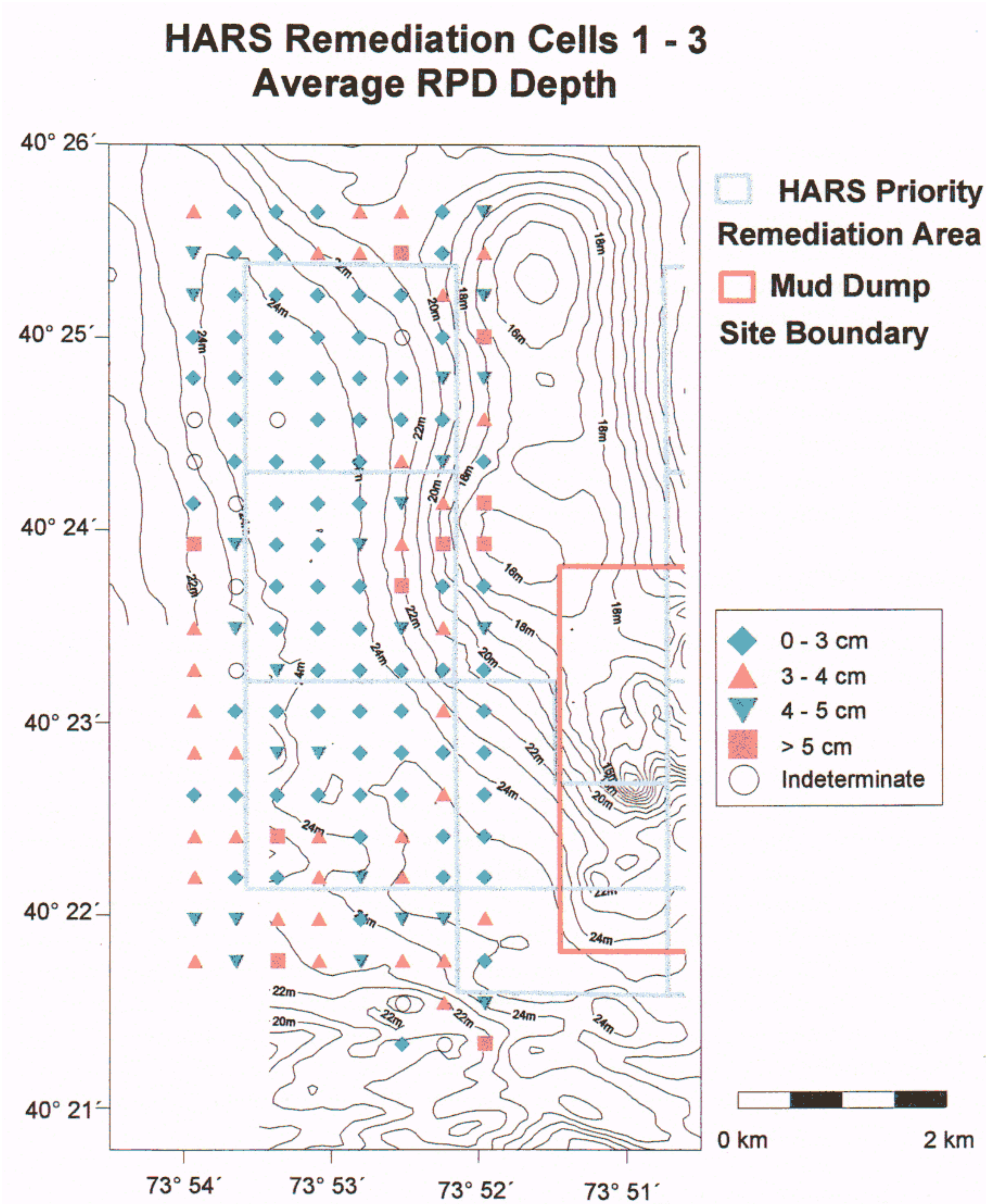


Figure 3-17. Redox Potential Discontinuity (RPD) depths in the HARS survey area as determined from REMOTS®.

sandy sediments, the depth of apparent RPD typically is measured as being equal to or greater than the prism penetration depth. This is considered preferable to designating the RPD as "indeterminate" because such a designation would result in an indeterminate Organism-Sediment Index value as well (i.e., for each image, the RPD must be measured for the OSI to be calculated). If too many stations in an area have indeterminate RPD and OSI values, the resultant seafloor maps become greatly reduced in value. Stations with rippled sand located in the northeast and southwest corners of the survey area were associated with relatively deep (i.e., greater than 3 cm) apparent RPD depths (Figure 3-17). The majority of RPD depths at stations with fine-grained, relic dredged material located within the elongated basin were in the range 0 to 3 cm (Figure 3-17), and there was typically a distinct color change between the light colored sediment at the surface and the black, highly-reduced sediment at depth (e.g., Figures 3-10a and 3-16a). Generally speaking, RPD depths less 3 cm are considered shallow. It is assumed that when the relic dredged material in the basin was first deposited in the past, the entire sediment column consisted of black, highly-reduced sediment. Normally, bioturbation by infaunal Stage III organisms would serve to enhance deepening of the RPD within the deposited fine-grained sediment, however, the infaunal successional stage map (Figure 3-15) helps to show that Stage III was rarely observed at the stations within the elongated basin.

Organism-Sediment Index

Organism-Sediment Index (OSI) values could not be calculated at several of the sand and gravel stations because the successional stage and/or RPD were indeterminate; small clusters of stations with indeterminate OSI values occurred primarily along the western boundary and in the southeast corner of the surveyed area (Figure 3-18). OSI values within the surveyed area generally ranged from +2 to +11, with the majority of values being less than or equal to +7 (Figure 3-19). Values greater than or equal to +6 typically reflect relatively deep RPD depths (>3.0 cm) and the presence of Stage I or III organisms; such values are considered indicative of benthic habitat conditions which are healthy or non-stressed. Most of the values greater than or equal to +6 were found at stations in the northeast and southwest corners of the surveyed area, representing the sloped sides of the elongated basin where sand was prevalent and RPD depths, in turn, were deeper (Figure 3-18). Stations with fine-grained, relic dredged material located within the elongated basin generally had average RPD depths less than 3 cm and only Stage I organisms present, resulting in low to intermediate OSI values between 0 and +6 (Figure 3-18). Such OSI values generally are considered indicative of benthic habitat conditions which are unhealthy or stressed.

3.2 Characterization of the Reference Areas

3.2.1 South Reference Area (SREF)

Both fine (3-2 phi) and very fine (4-3 phi) rippled sands were found in the SREF area (Figure 3-20). These results are generally consistent with those of past monitoring

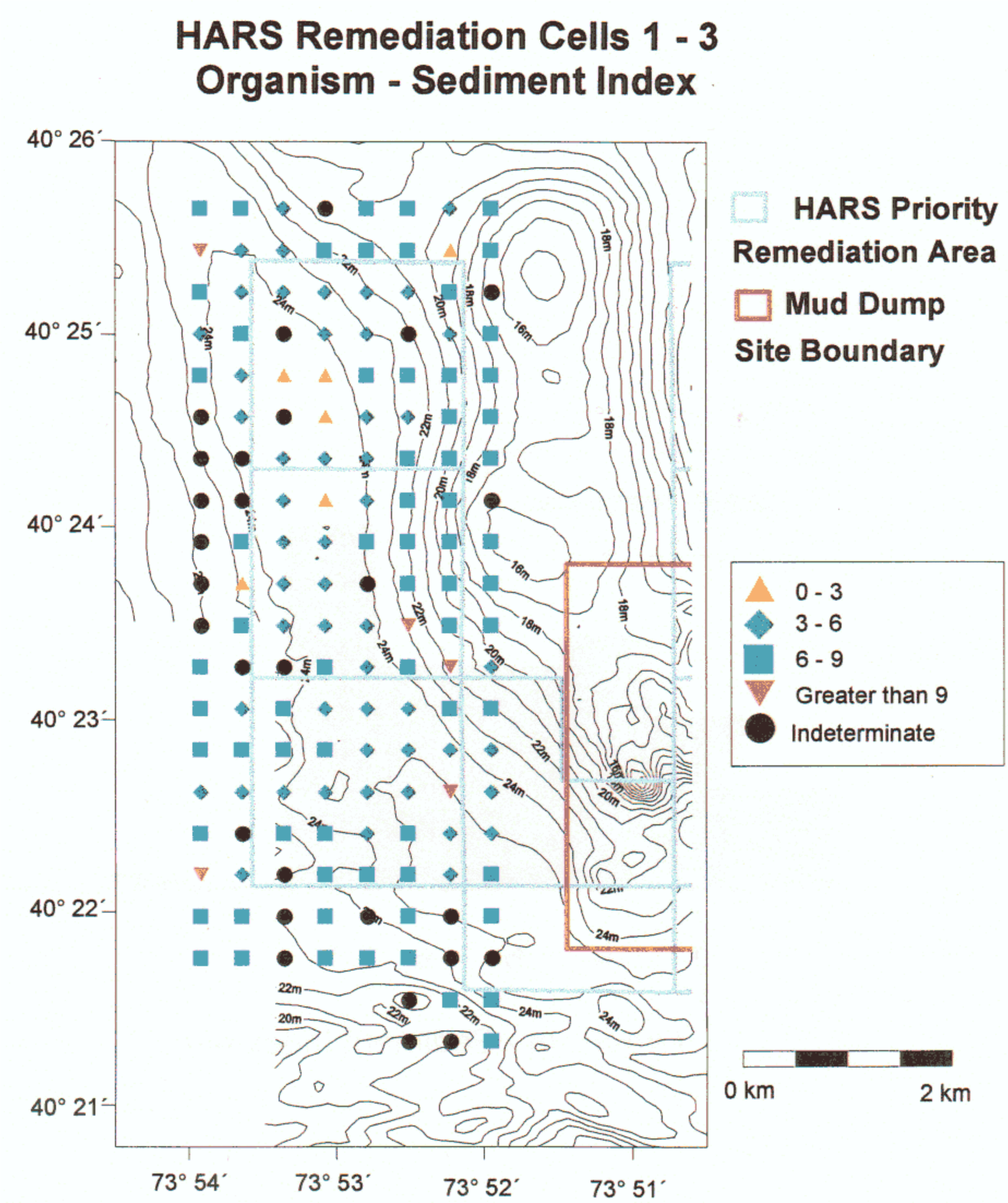


Figure 3-18. Map of average Organism Sediment Index (OSI) values at stations in the surveyed area at HARS.

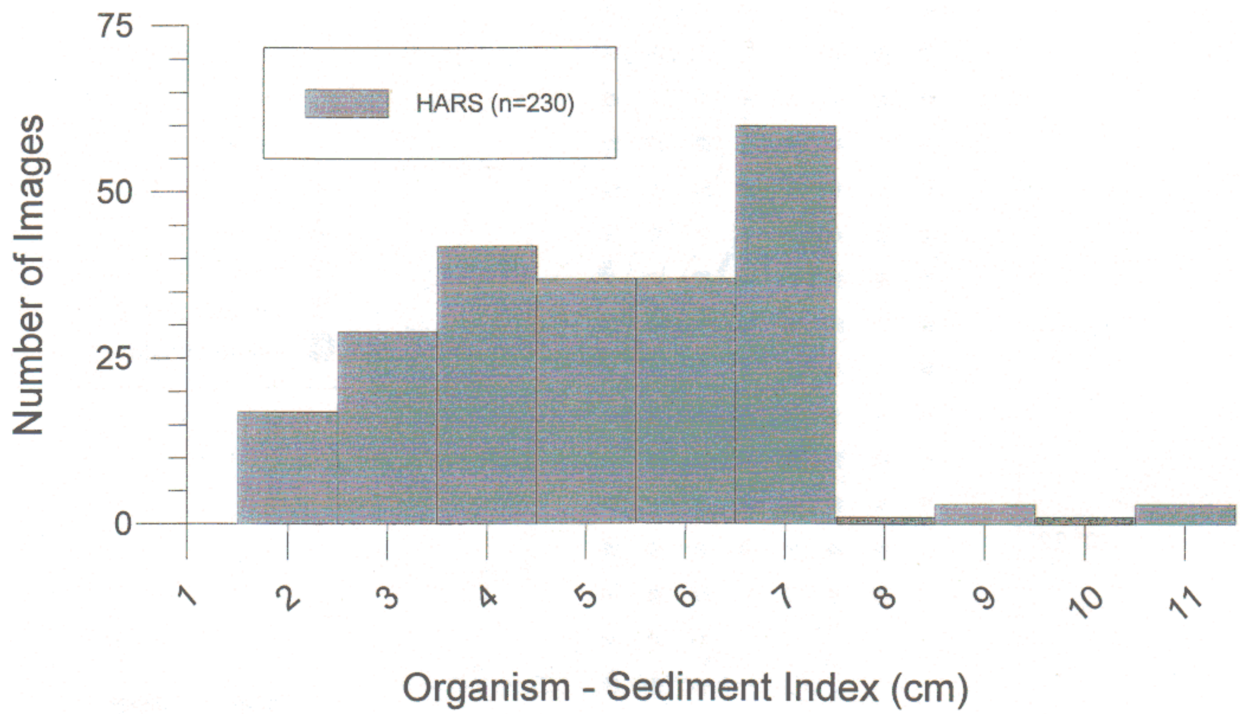


Figure 3-19. Frequency distribution of Organism-Sediment Index values for all replicate REMOTS® images obtained in the HARS survey area.

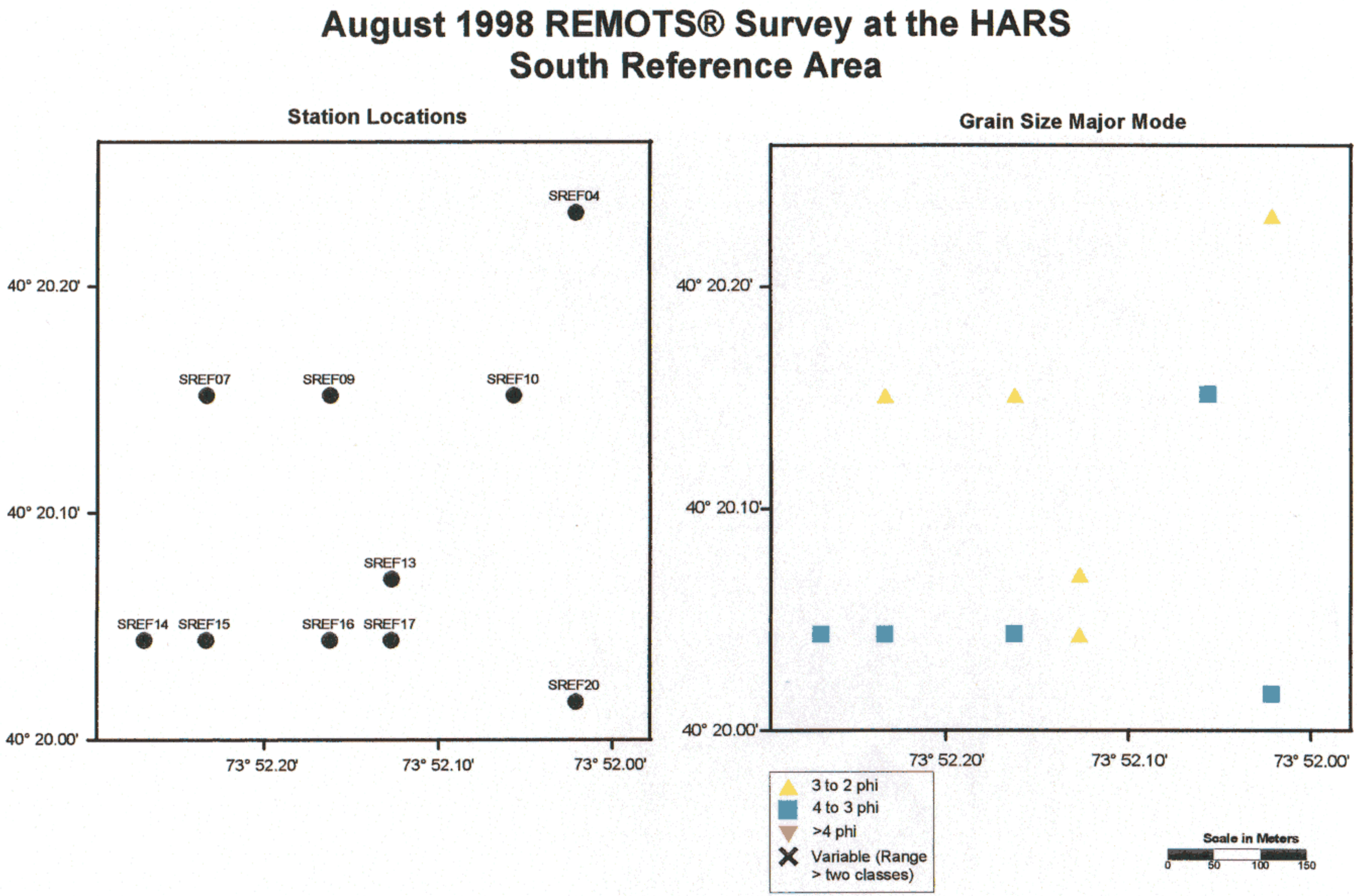


Figure 3-20. Maps showing station names and grain size major mode at the South Reference Area (SREF) stations.

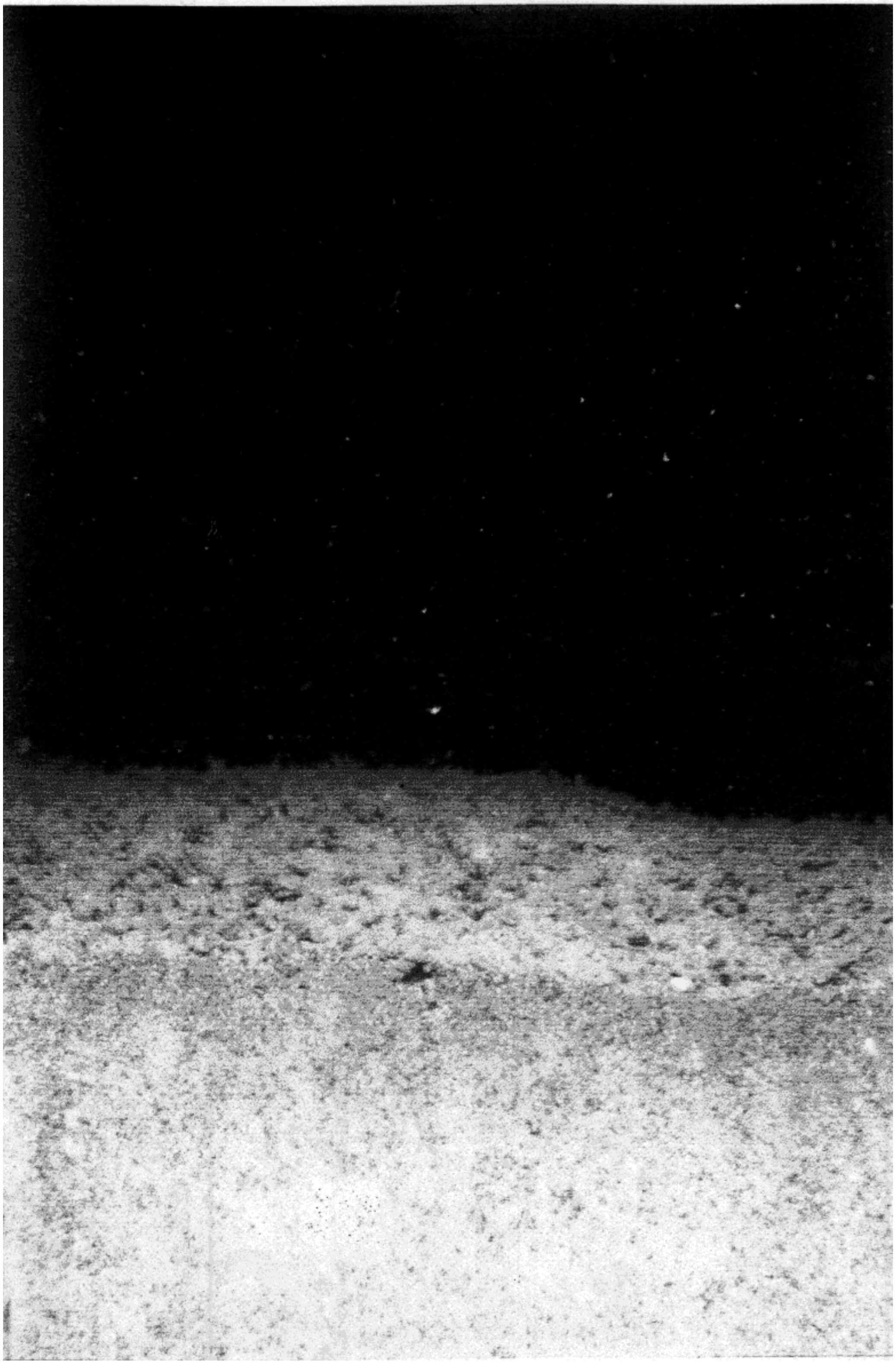


Figure 3–21. REMOTS® image of SREF station 13 showing a layer of flocculant organic matter at the sand surface, which in turn is supporting a dense assemblage of surface-dwelling polychaete tubes.

surveys, which have shown fine rippled sands, representing ambient New York Bight sediments, to predominate in this area. Generally, there was a higher proportion of fine-grained sediment and flocculant organic matter at the sand surface than observed in previous surveys (Figure 3-21). The presence of this significant accumulation of fine, flocculant material on the surface of the rippled sand is evidence of an extended quiescent period in the months preceding the survey. The presence of this finer material has resulted in a subtle shift in apparent grain size from fine to very fine sand at some of the SREF stations. In this survey, there was no dredged material detected in any of the images obtained in the SREF area (Figure 3-22). Relic dredged material had been observed underlying clean fine sand at station SREF-17 in previous surveys; it is likely that this material occurs in relatively small, discrete patches in the vicinity of station SREF-17 and these patches are not consistently sampled by the REMOTS® camera from survey to survey.

Average RPD depths at the SREF stations were relatively well-developed (i.e., > 3 cm), reflecting the presence of well-aerated, rippled sand (Figure 3-22). Stage I, consisting of surface-dwelling, tubicolous polychaetes, was the dominant successional stage at all stations in the SREF area (Figure 3-23). This is generally consistent with the results of previous surveys. However, at all stations the Stage I polychaete tubes occurred at noticeably higher densities in this survey than in previous ones (Figures 3-21 and 3-24). This again is attributed primarily to the apparent quiescent conditions in the weeks and months preceding the survey. In the absence of significant storm-induced near-bottom currents, a significant accumulation of organic matter and dense aggregations of associated surface-dwelling, opportunistic organisms had become well-established at the sediment surface.

Organism-Sediment Index values at SREF stations generally ranged from 6 to 9; these are intermediate to high values indicative of good overall benthic habitat quality (Figure 3-23). This reflects the widespread presence of Stage I organisms and the relatively deep RPD values determined in the rippled sands at the SREF stations, which are consistent with past results.

3.2.2 Candidate Reference Area NREF-2

Nine of the stations at candidate reference area NREF-2 were arranged in a cross-shaped pattern and spaced 100 m apart, with four addition stations located 100 m from the center at the NW, NE, SW and SE positions (Figure 3-25). Silt-clay (>4 phi) was the dominant sediment type found at all of the stations (Figure 3-25). The presence of fine-grained sediments in this area was contrary to expectations, as examination of NOAA Chart 12326 suggested that medium sand would be found.

The fine-grained sediment generally had the appearance of relic dredged material, characterized by extremely low reflectance at depth (i.e., black color) and shallow RPD depths, both indicative of high organic content (Figure 3-26). However, since this candidate reference area is located several kilometers from the Mud Dump Site, the origin

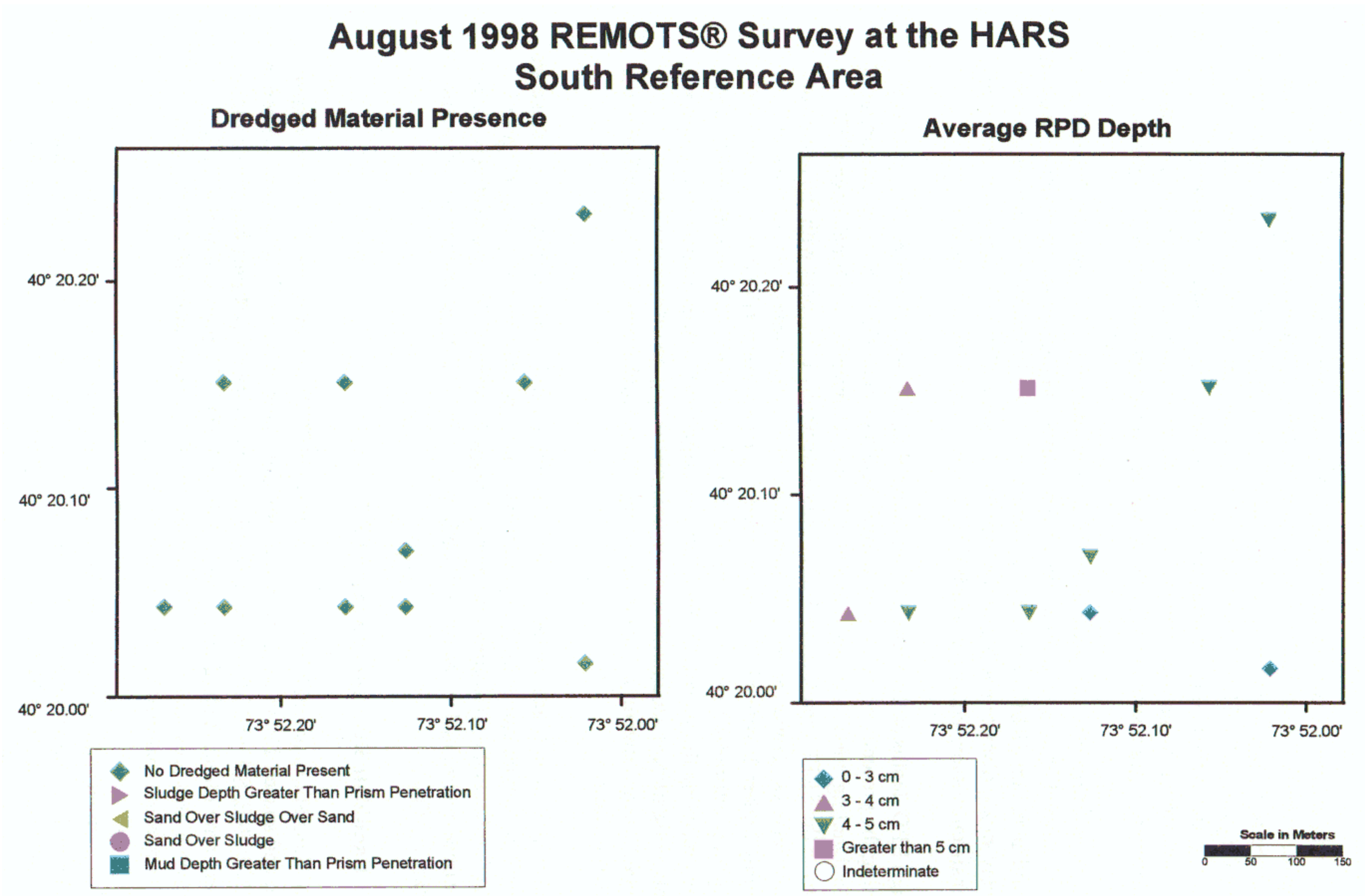


Figure 3-22. Maps show

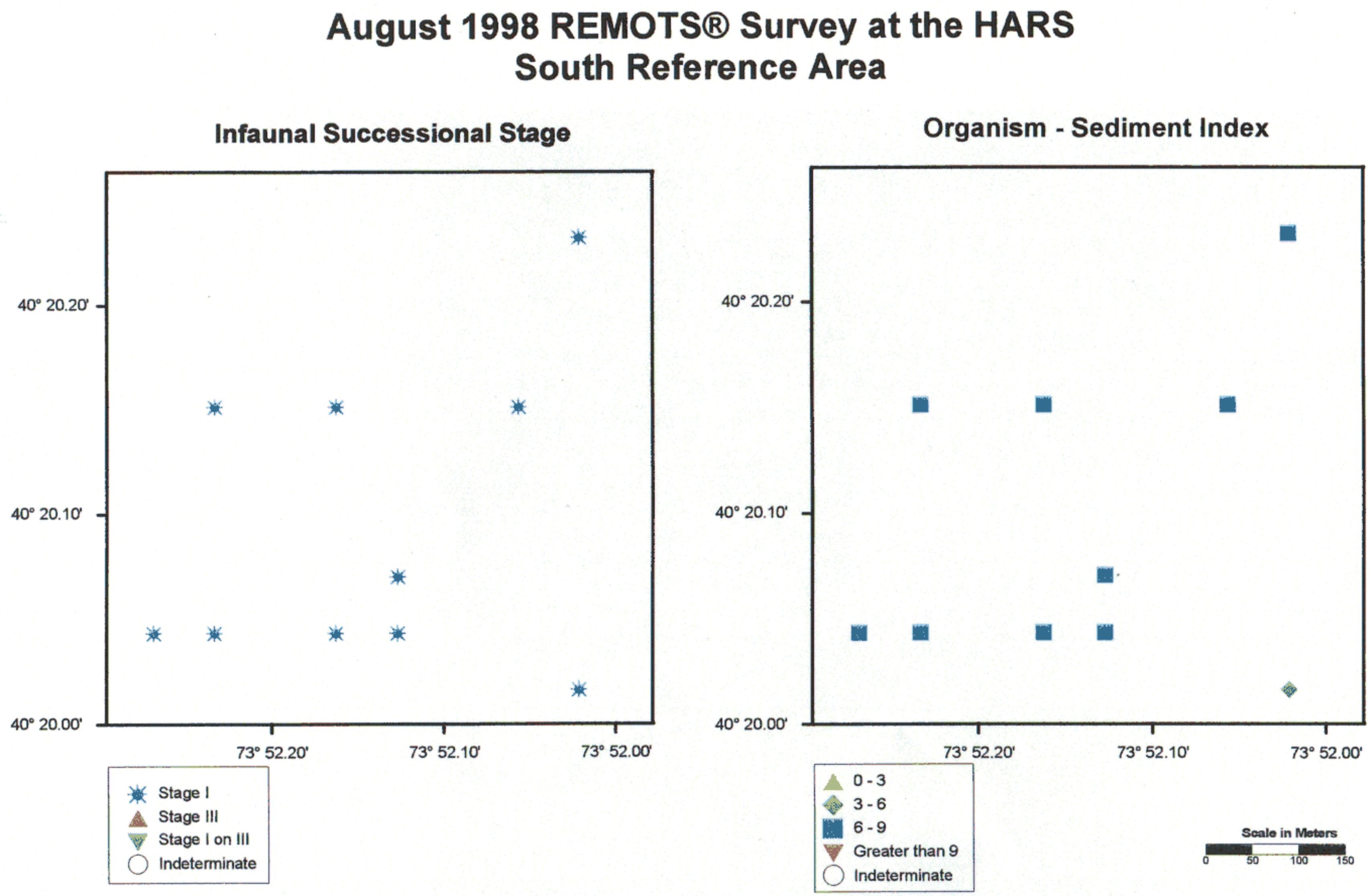


Figure 3-23. Maps showing infaunal successional stages and average Organism-Sediment Index values at the South Reference Area (SREF) stations.

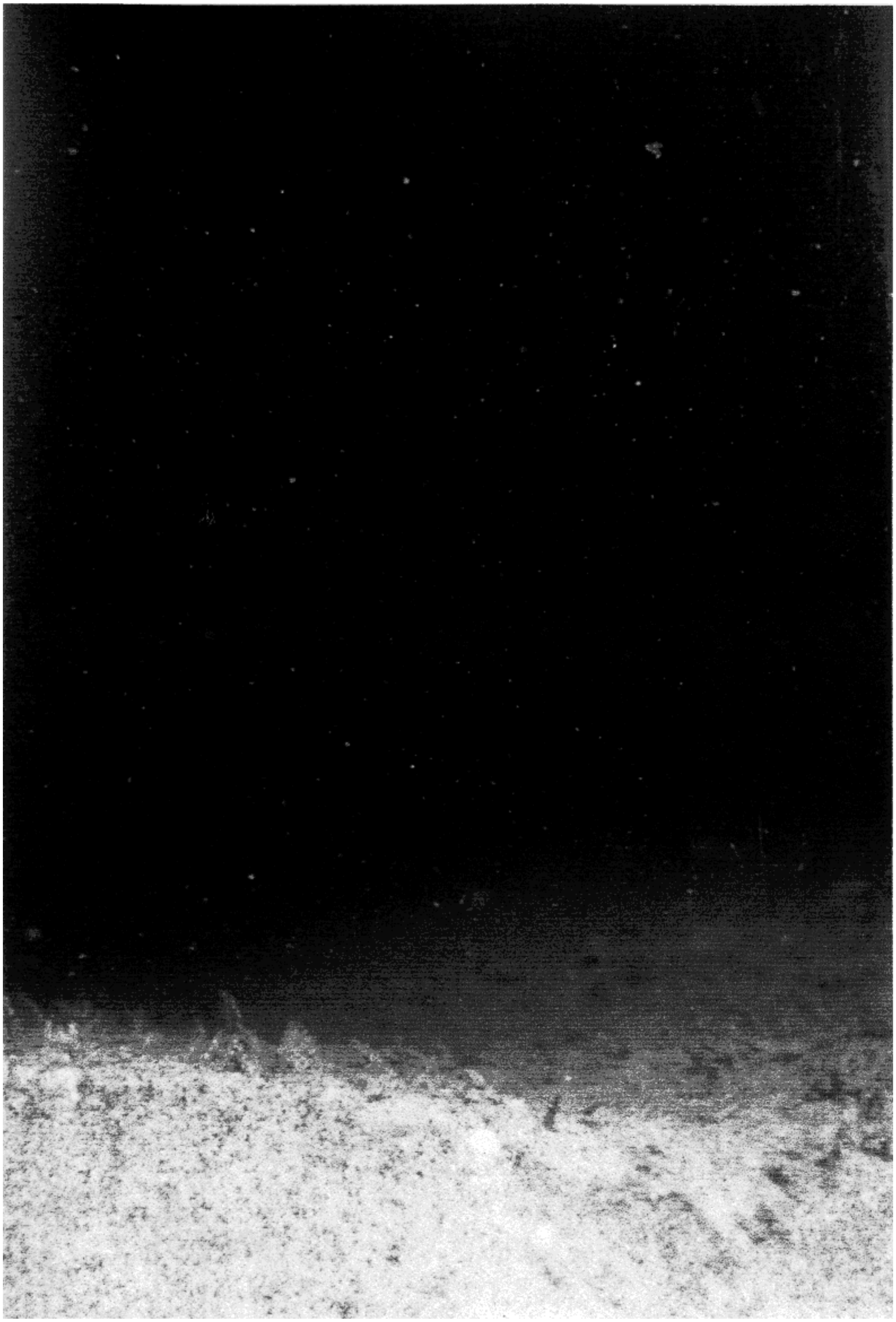


Figure 3-24. REMOTS image of SREF station 7 illustrating a dense aggregation of Stage I polychaete tubes at the sediment surface.

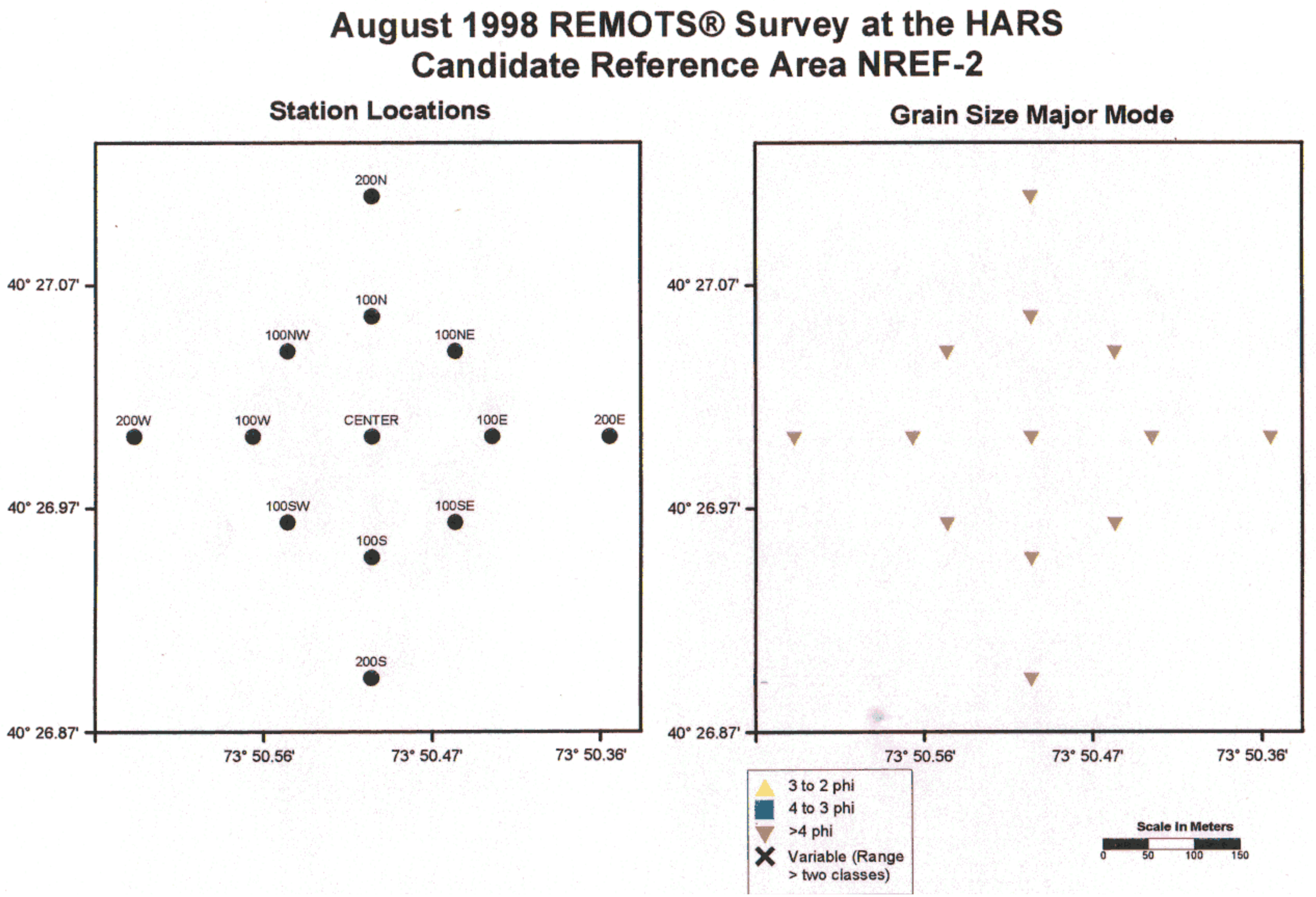


Figure 3-25. Maps showing station names and grain size major mode at candidate reference area NREF-2 stations.

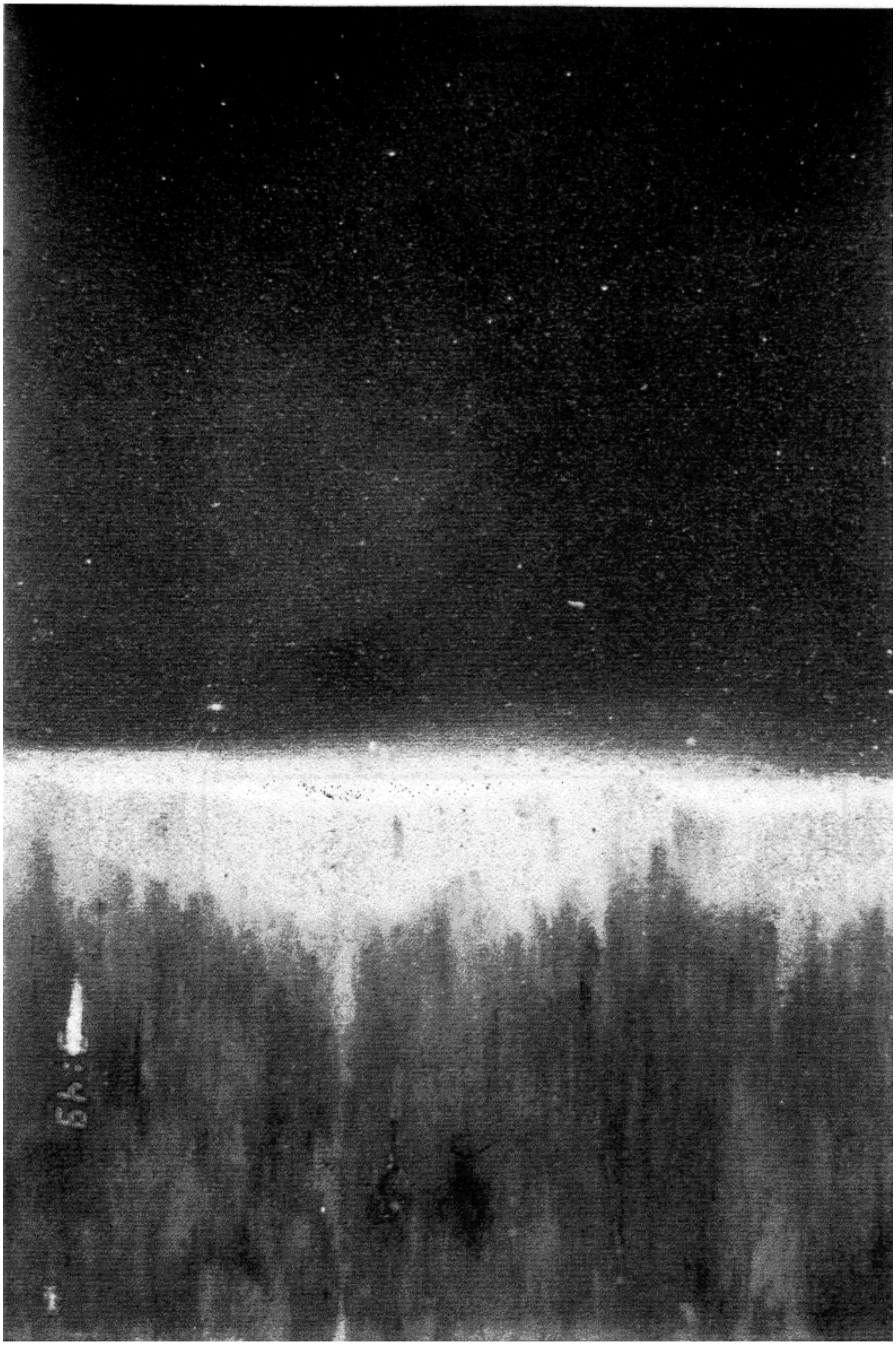


Figure 3-26. Representative REMOTS image (from station NREF-CTR) showing the low-reflectance, fine-grained sediment found at all stations in the NREF candidate reference area. This sediment may be relic dredged material, sewage sludge, or naturally-deposited silt-clay with high organic content.

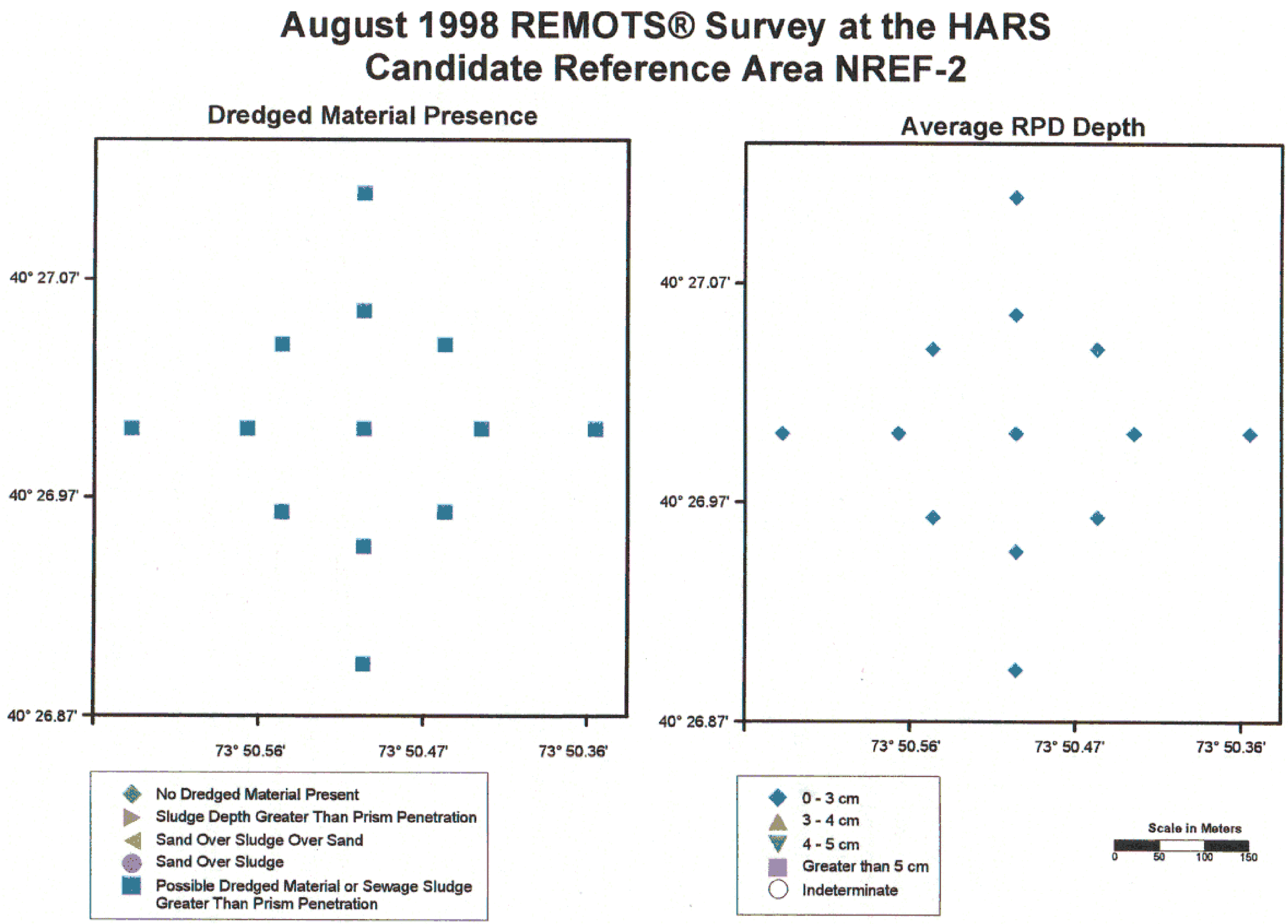


Figure 3-27. Maps showing dredged material presence and average RPD depths at the candidate reference area NREF-2 stations.

of the fine-grained sediment is uncertain. One possibility is that the material is, in fact, relic dredged material resulting from historic disposal in this location. Another possibility is that some fraction of the black fine-grained material represents sewage sludge transported from the Sewage Sludge Dump Site, which is located to the southeast. Alternately, the sediment may simply represent naturally deposited fines transported either by the Hudson River plume or from elsewhere within the New York Bight. The map of dredged material presence reflects the uncertainty regarding the origin of the fine-grained material at NREF-2 (Figure 3-27). As indicated above, average RPD depths at all stations were generally shallow (< 3 cm, Figure 3-27). This reflects both the high apparent organic content of the sediment, and the general absence of Stage III organisms at most stations (Figure 3-28). Stage I was the dominant successional stage at all stations except 200S and 100SE (Figure 3-28). In the absence of widespread bioturbation by Stage III infaunal organisms at stations having fine-grained, organically enriched sediments, RPD depths are likely to remain shallow. The shallow RPD depths and dominance by Stage I organisms are reflected in OSI values which generally ranged from 3 to 6 at the majority of stations (Figure 3-28). These are intermediate OSI values reflective of a habitat which might be considered moderately degraded.

3.2.3 Candidate Reference Area R-2

The nine stations at candidate reference area R-2 were arranged in a cross-shaped pattern and spaced 100 m apart (Figure 3-29). Very fine sand (4-3 phi) with a significant silt-clay fraction was the dominant sediment type, except at two stations where silt-clay (>4 phi) was dominant (Figure 3-29). The muddy fine sand which characterized the area generally had the appearance of relic dredged material, based on very low optical reflectance at depth (i.e., black color) and relatively shallow RPD depths, both indicative of high organic content (Figure 3-30).

Candidate reference area R-2 is located within the Christiaensen Basin, a large-scale topographic depression at the head of the Hudson Canyon which functions in the New York Bight as a depositional site for fine-grained material (Figure 2-2). It is likely that some of the fine-grained surface sediment observed in the REMOTS® images from area R-2 is recently-deposited, ambient material. However, it likely that the deeper, black layers represent a sediment “reservoir” of sewage sludge resulting from past disposal at the Sewage Sludge Dump Site. This black, apparent sewage sludge was present at depth in the REMOTS® images at all of the R-2 stations (Figure 3-31).

At all of the stations except CENTER, average RPD depths were shallow (< 3 cm, Figure 3-31), and Stage I was the dominant successional stage (Figure 3-32). The apparent scarcity of Stage III organisms in the fine-grained, organic rich sediment in this area may be due to the toxic effects of chemical contaminants in the sewage sludge. Since extensive bioturbation and resultant aeration of these sediments by Stage III organisms does not appear to be occurring, RPD depths remain shallow. The shallow RPD depths and dominance by Stage I organisms are reflected in OSI values which generally ranged

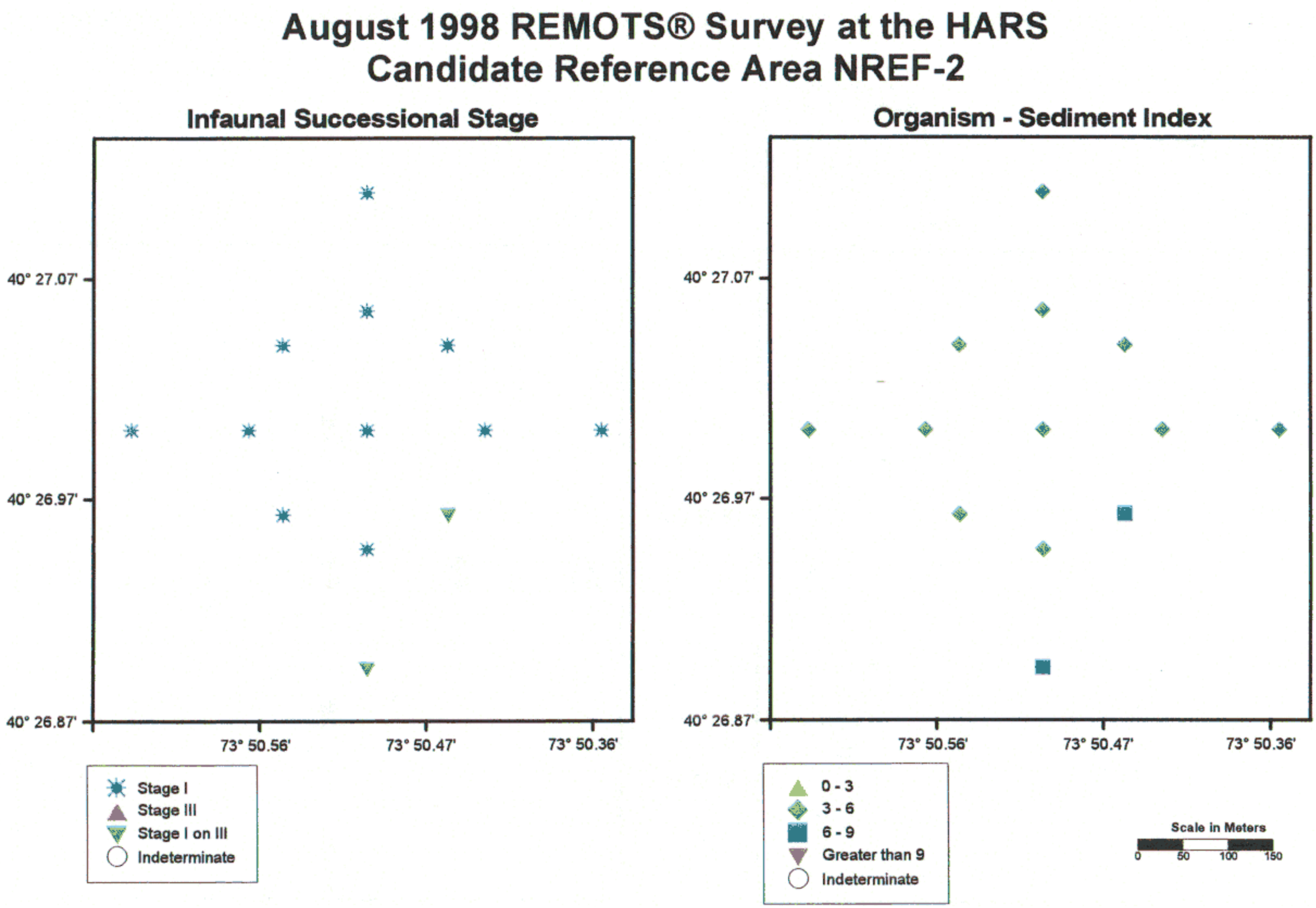


Figure 3-28. Maps showing infaunal successional stages and average Organism-Sediment Index values at the candidate reference area NREF-2 stations.

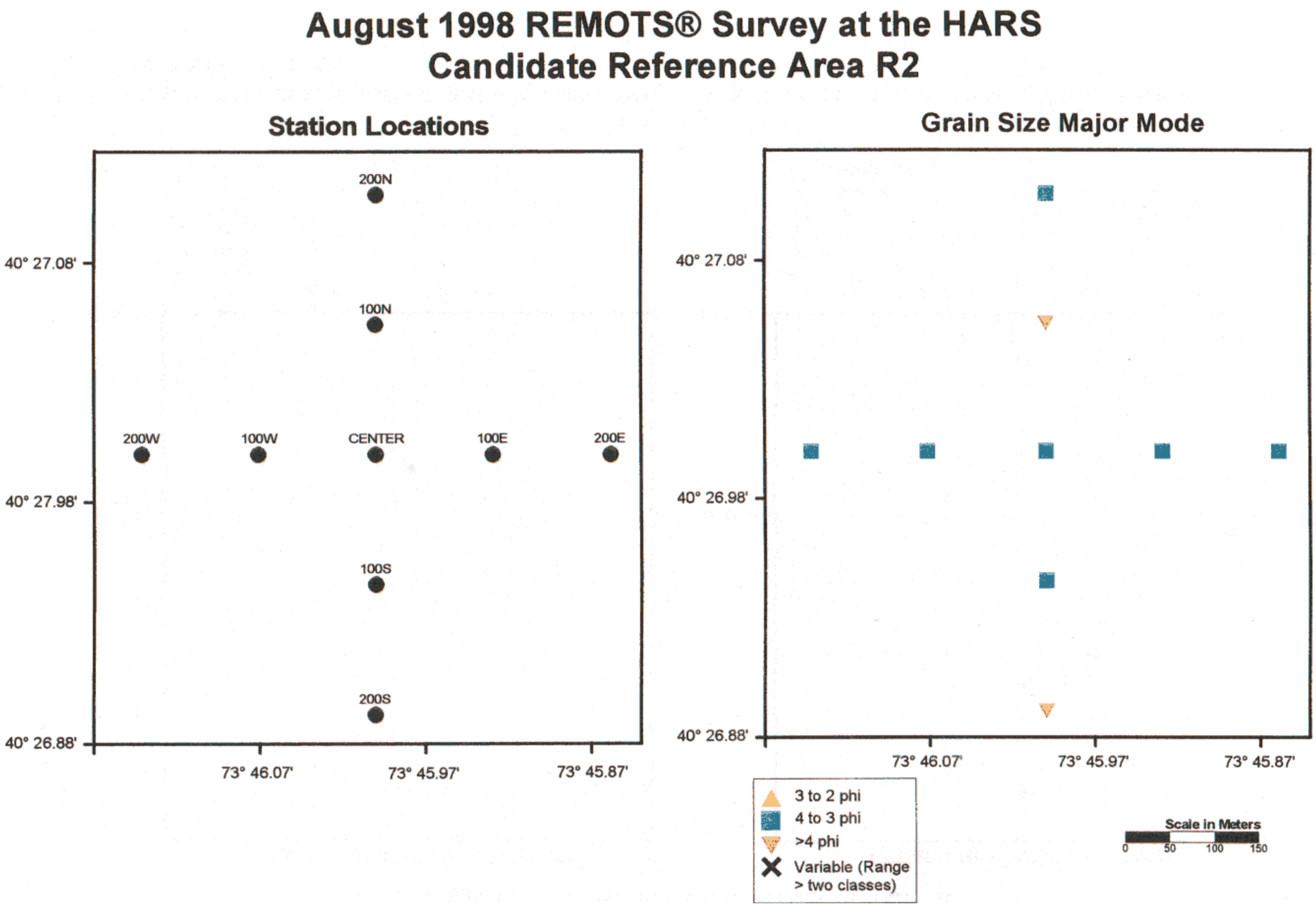


Figure 3-29. Maps showing station names and grain size major mode at the candidate reference area R-2 stations.

Figure 3-30. This REMOTS image from station 100N is representative of all the images obtained in candidate reference area R-2. A Stage I polychaete tube is visible at

the sediment surface, and black fine-grained material (possibly relic sewage sludge) occurs at depth.

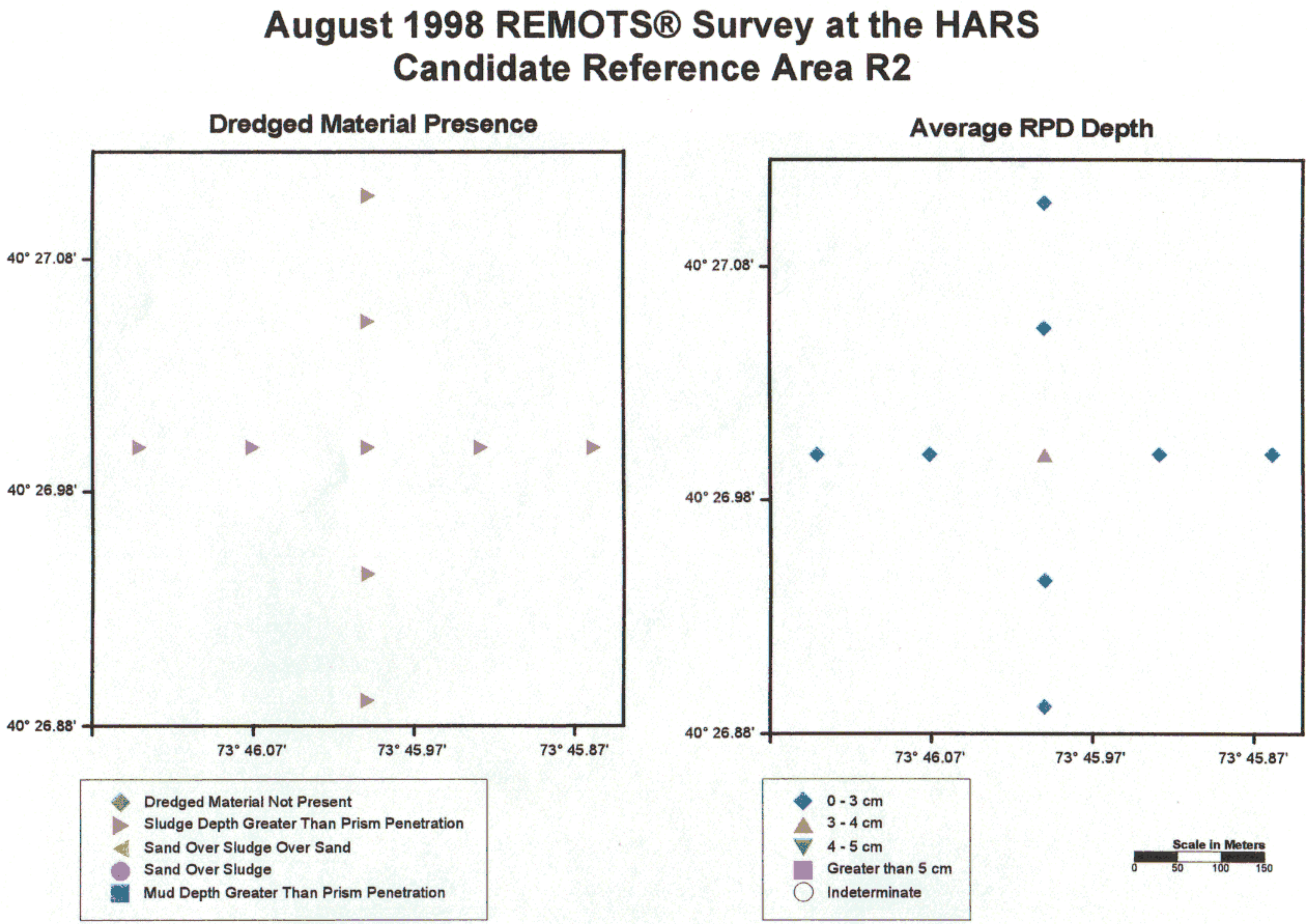


Figure 3-31. Maps showing dredged material presence and average RPD depths at the candidate reference area R-2 stations.

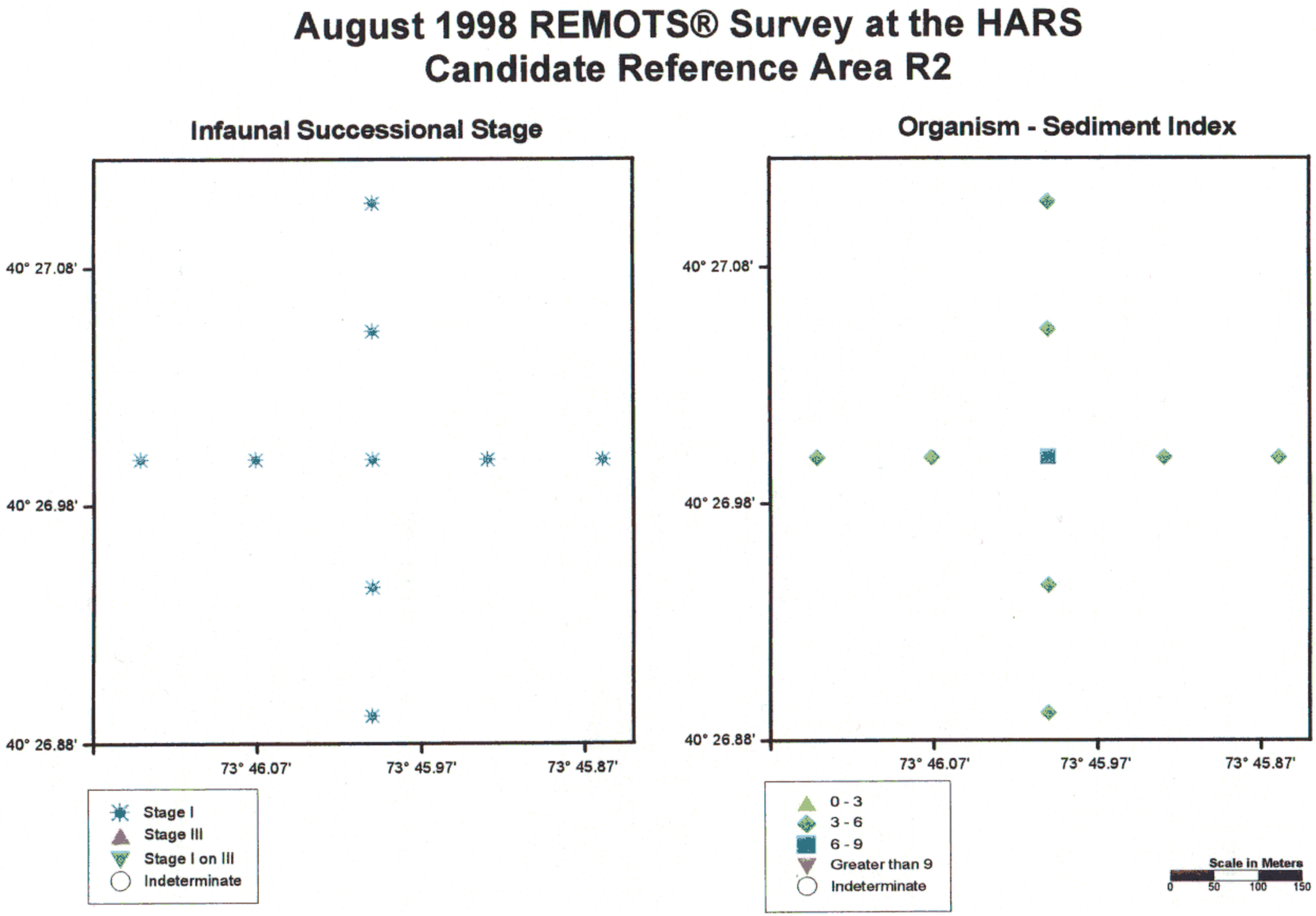


Figure 3-32. Maps showing infaunal successional stages and average Organism-Sediment Index values at the candidate reference area R-2 stations.

from 3 to 6 at the majority of stations (Figure 3-32). These are intermediate OSI values reflective of a habitat which might be considered moderately degraded.

3.2.4 Candidate Reference Area NY-6

The REMOTS® results for candidate reference area NY-6 are very similar to those described above for area R-2. The nine stations at NY-6 were arranged in a cross-shaped pattern and spaced 100 m apart, and very fine sand (4-3 phi) with a significant silt-clay fraction was the dominant sediment type at all stations (Figure 3-33).

Like R-2, candidate reference area NY-6 is located within the Christiaensen Basin, very close to the northwest corner of the former Sewage Sludge Dump Site (Figure 2-2). Therefore, while some of the fine-grained sediment near the surface at NY-6 could be naturally deposited material, it is likely that the black coloration observed at depth is related to historic inputs of sewage sludge from the nearby disposal site. Similar to candidate area R-2, this apparent sludge signature was found at all of the NY-6 stations (Figure 3-34). In most of the images, the black material occurred at depth underneath a sandy surface layer (Figure 3-35). In some images, the black material occurred as a distinct horizon within a sandy sediment matrix (Figure 3-36).

With the exception of station 100E, average RPD depths at NY-6 were generally shallow (< 3 cm, Figure 3-34), and Stage I was the dominant successional stage (Figure 3-37). The shallow RPD depths and dominance by Stage I organisms are reflected in OSI values which generally ranged from 3 to 6 at the majority of stations (Figure 3-37). As at candidate reference area R-2, these are intermediate OSI values reflective of a habitat which might be considered moderately degraded. The apparent scarcity of Stage III organisms in this area may be due to the toxic effects of chemical contaminants in the sewage sludge.

3.2.5 Candidate Reference Area DEEP-REF

A cross-shaped sampling pattern with nine stations also was utilized at candidate reference area DEEP-REF; this relatively deep area within Hudson Canyon was found to be dominated by silt-clay sediments having a major mode of >4 phi (Figure 3-38). The penetration of the REMOTS® camera prism at the DEEP-REF stations was noticeably greater than at the other candidate reference areas, probably reflecting a higher sediment water content (lower density) and overall softer (i.e., finer-grained) sediment texture (Figure 3-39). Although the sediment at depth had a dark color, suggesting a high inventory of organic carbon, the lack of nearby sources tends to preclude the possibility that this sediment is relic dredged material. Rather, it is assumed that this fine-grained sediment represents ambient material (i.e., naturally-occurring silt-clay; Figure 3-40).

Most of the DEEP-REF stations had relatively shallow RPD depths (< 3 cm; Figure 3-40), but all except two had Stage I on III successional designations (Figure 3-41). The shallow RPD depths may be due to this depositional site receiving relatively high amounts of organic matter, both directly from the overlying water column and transported from shallower depths on the surrounding seafloor. A high input of organic carbon would also help to explain the existence of an apparently healthy, equilibrium benthic community comprised of both Stage I and III seres. Organism-Sediment Index values were greater than +6 at 7 of the 9 stations (Figure 3-41), which is indicative of good overall benthic habitat quality and mainly reflects the widespread occurrence of Stage III organisms.

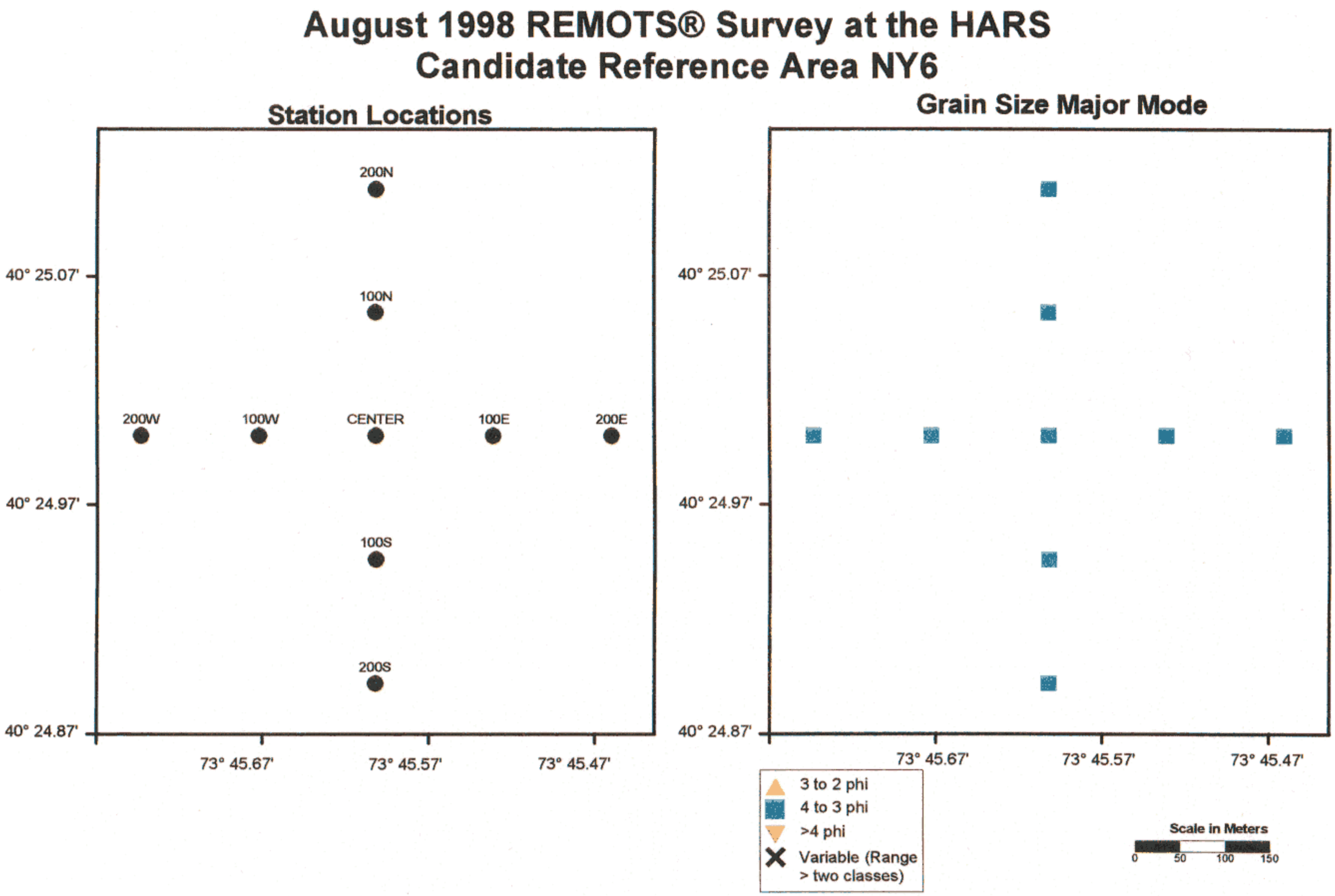


Figure 3-33. Maps showing station names and grain size major mode at the candidate reference area NY-6 stations.

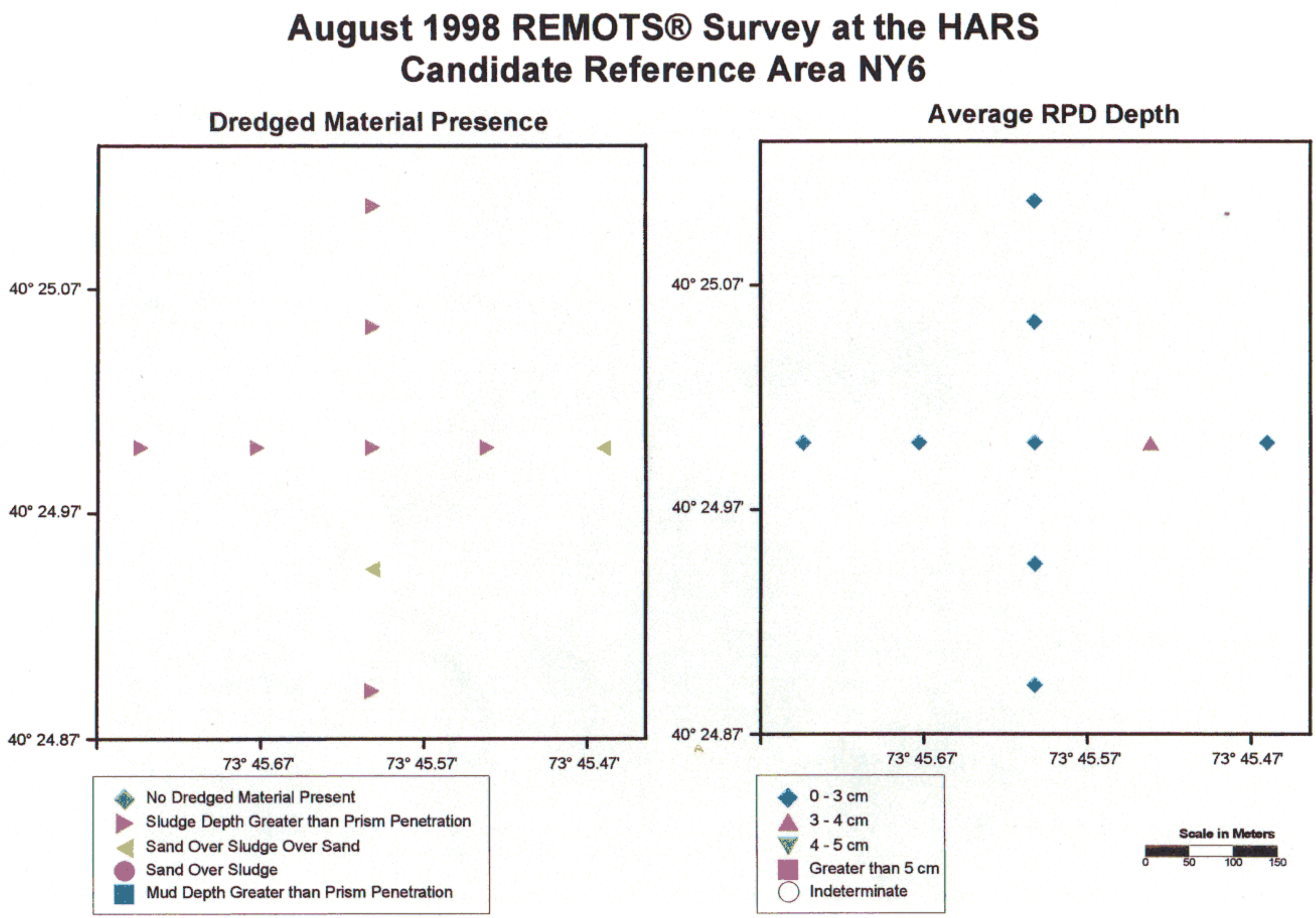


Figure 3-34. Maps showing dredged material presence and average RPD depths at the candidate reference area NY-6 stations.

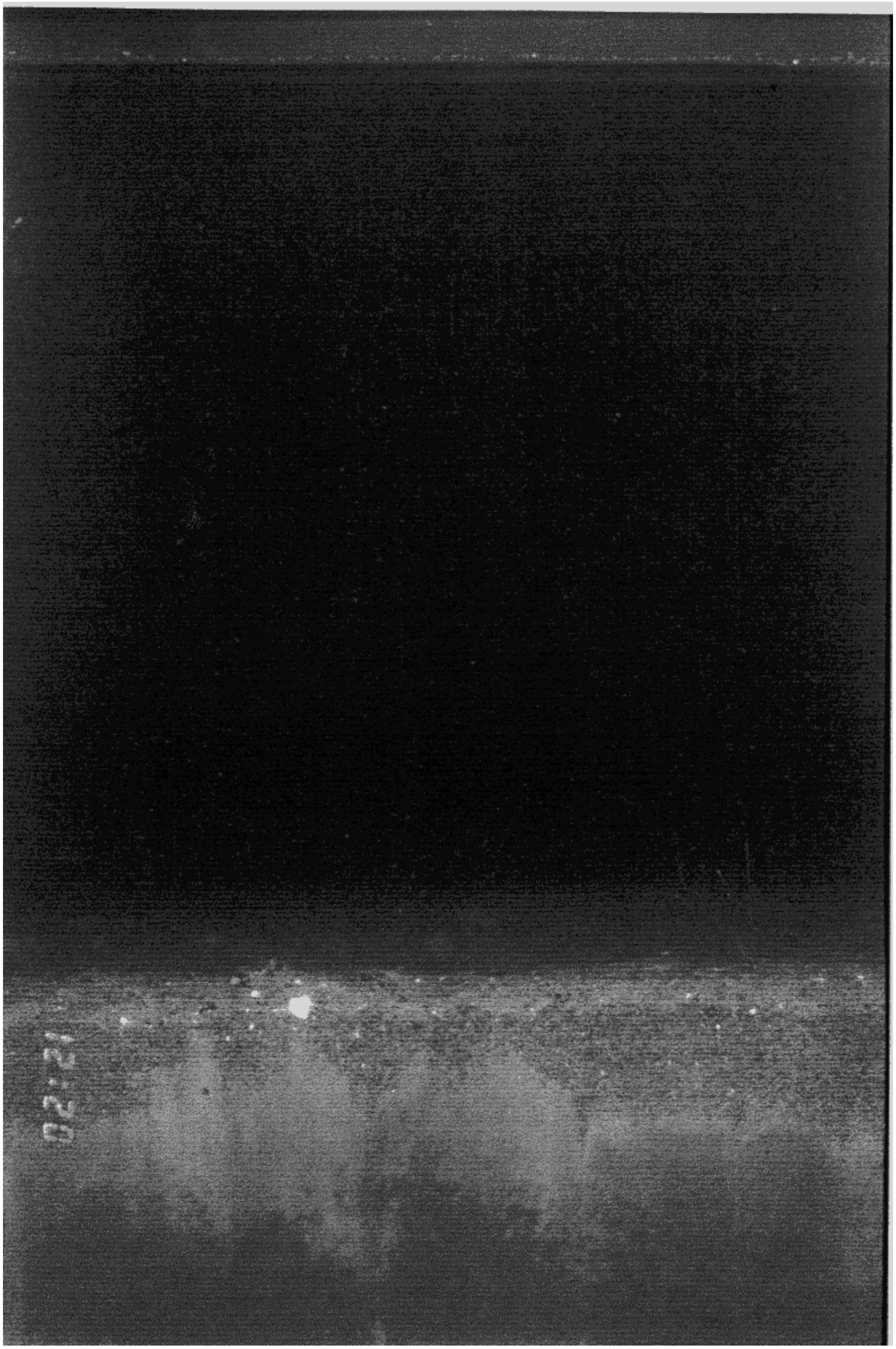


Figure 3-35. Representative REMOTS® image from candidate reference area NY-6, station 200E. Under a sandy surface layer, the black, fine-grained material at depth is possible sewage sludge.

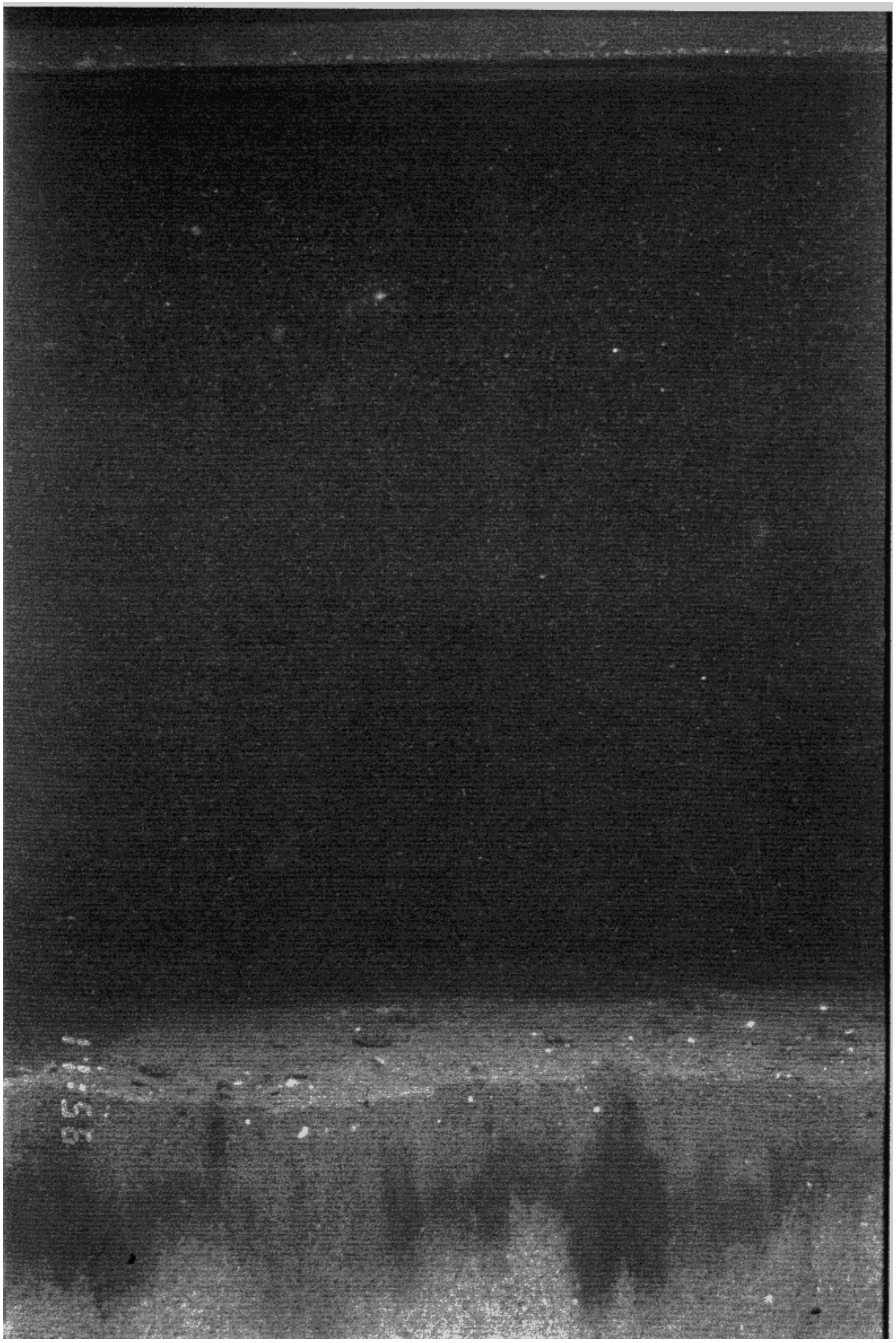


Figure 3-36. REMOTS® image from candidate reference area NY-6, station 100S, showing a thin layer of black fine-grained material within a fine sand matrix.

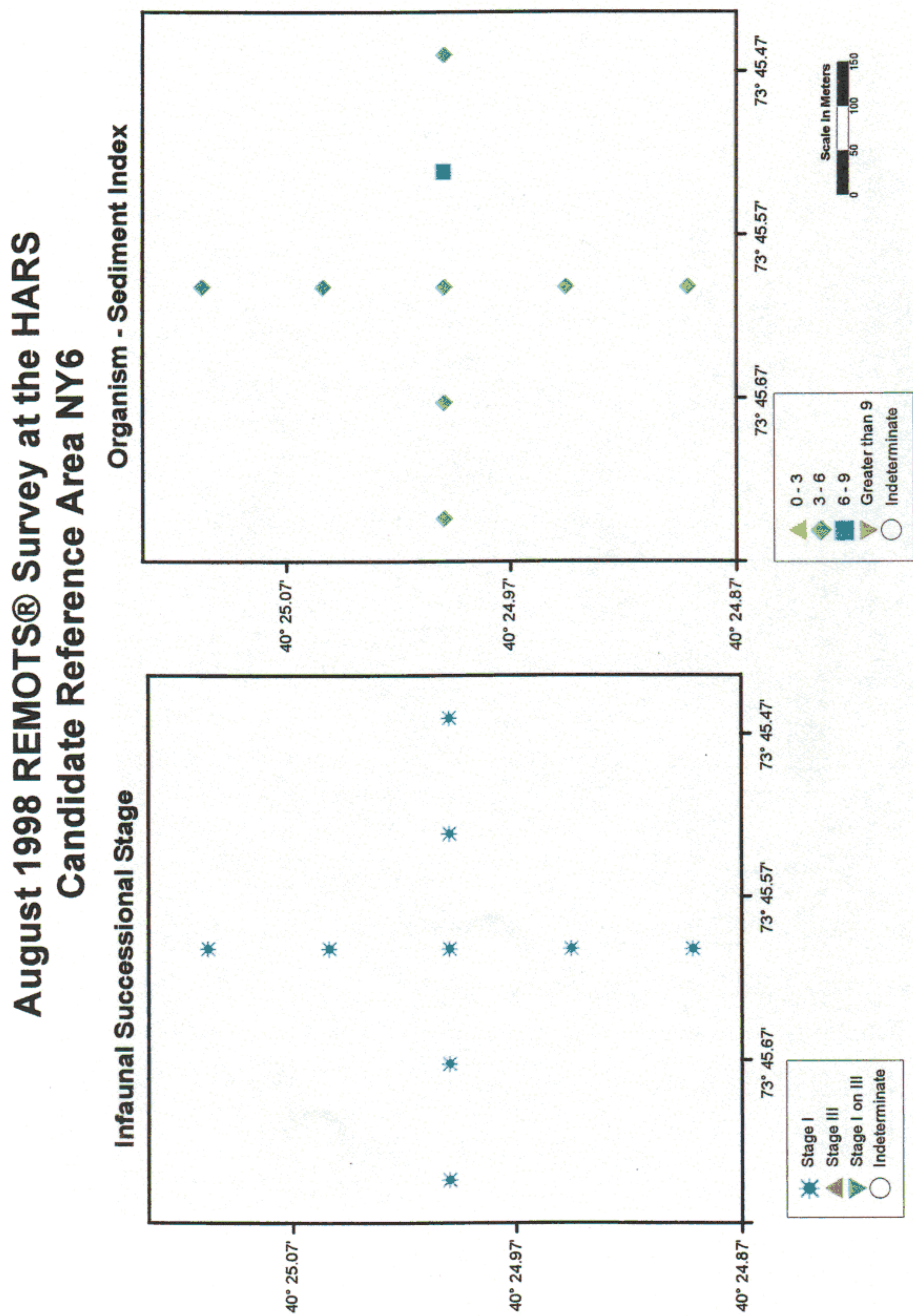


Figure 3-37. Maps sh
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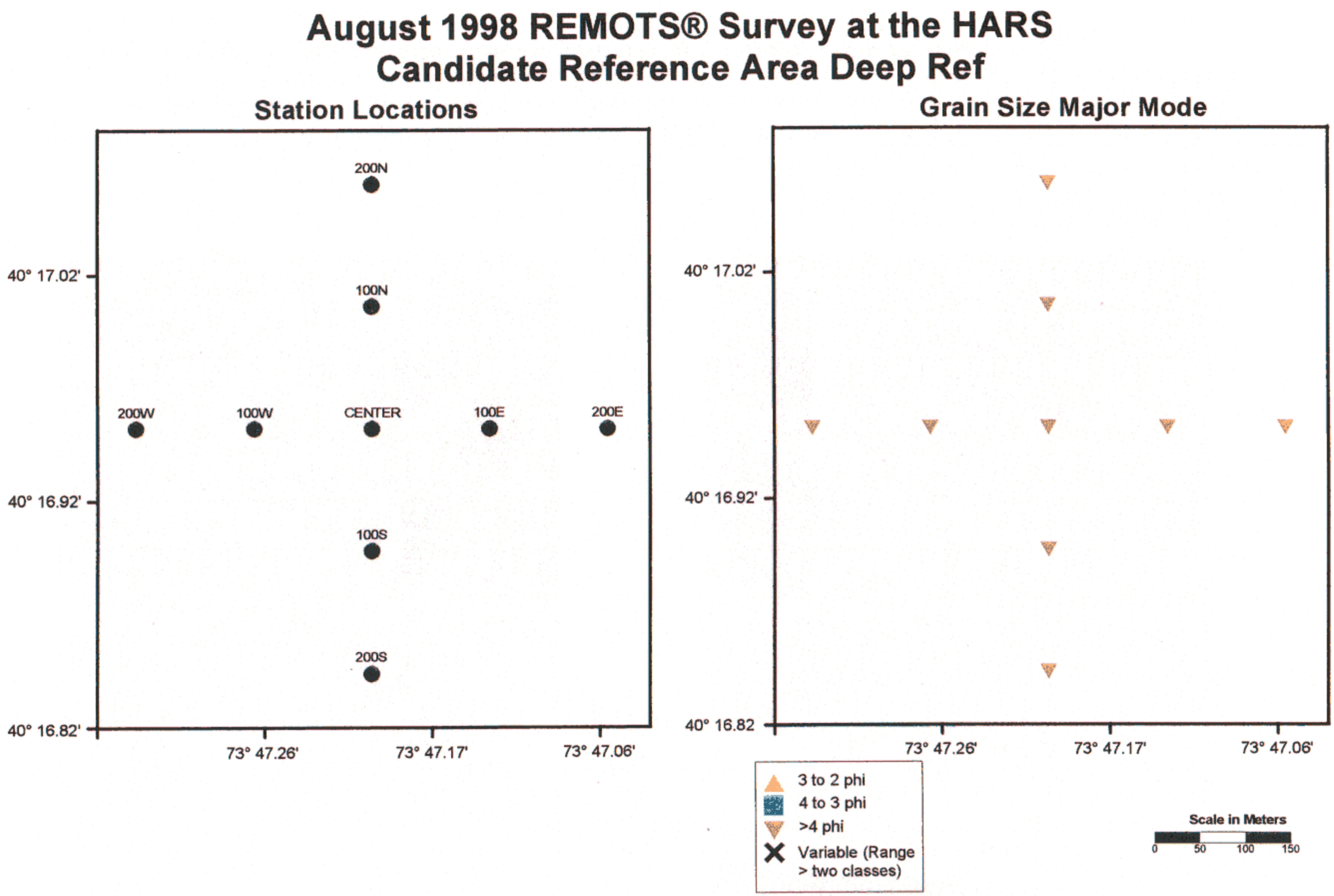
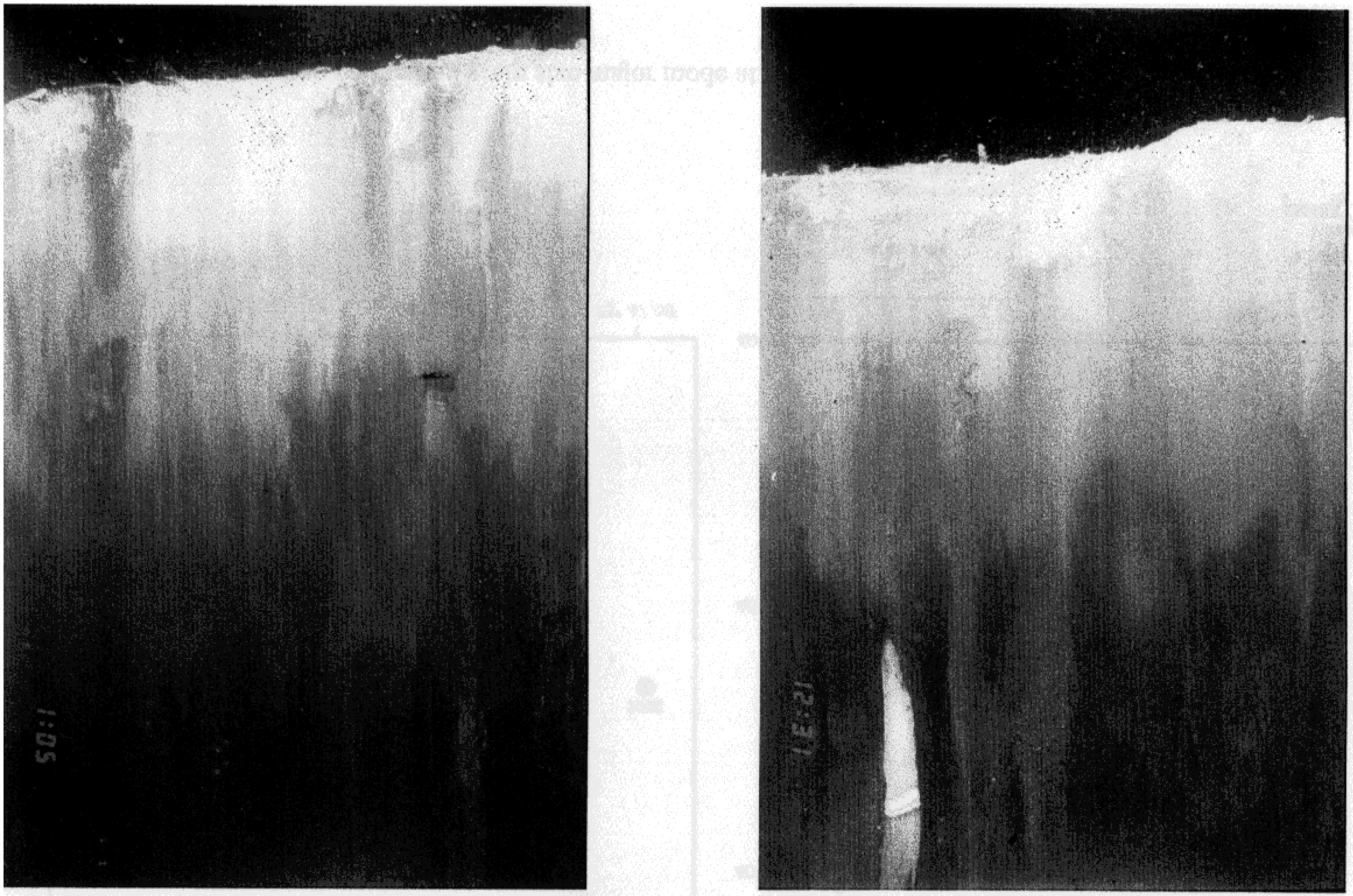


Figure 3-38. Maps showing station names and grain size major mode at the candidate reference area DEEP-REF stations.



A B

Figure 3-39. Two REMOTS® images illustrating the relatively deep penetration of the REMOTS® camera prism at DEEP-REF stations compared to the other candidate reference areas.

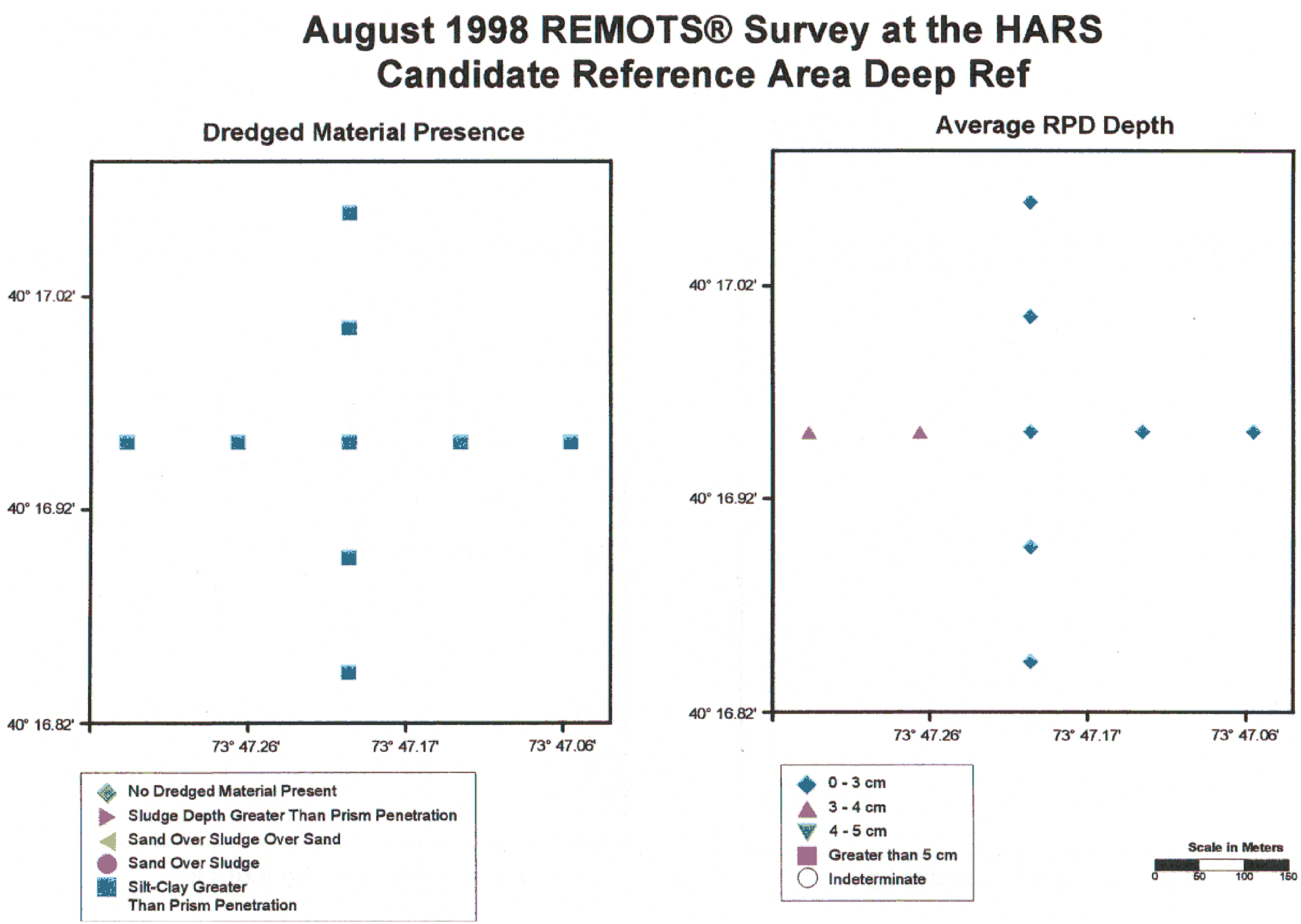


Figure 3-40. Maps showing dredged material presence and average RPD depths at the candidate reference area DEEP-REF stations.

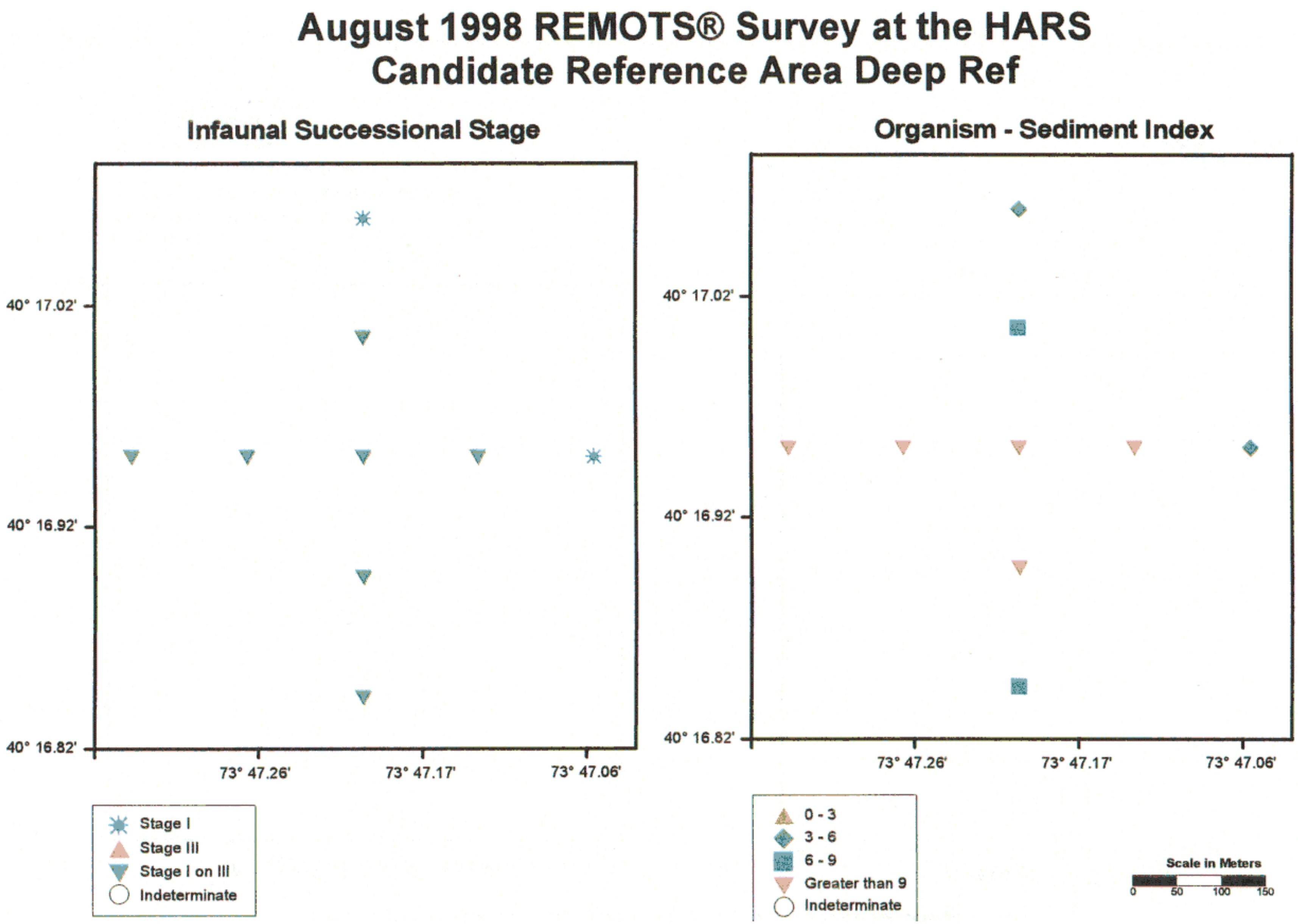


Figure 3-41. Maps showing infaunal successional stages and average Organism-Sediment Index values at the candidate reference area DEEP-REF stations.

4.0 DISCUSSION

In the August 1998 REMOTS® survey of the HARS, stations were arranged in a rectangular grid pattern to provide high-resolution spatial coverage of remediation cells 1, 2 and 3, and the surrounding buffer zone. The primary objective of the survey was to characterize physical and biological seafloor conditions and assess benthic habitat quality in this region, prior to the commencement of capping operations expected to occur over the next several years. Similar high-resolution REMOTS® surveys of the other HARS remediation cells will occur in the future once capping operations in remediation cells 1, 2 and 3 near completion. A second objective of the August 1998 survey was to characterize seafloor conditions in several candidate reference areas and evaluate their suitability for use in future HARS monitoring efforts. The results are discussed below in relation to the two survey objectives.

4.1 Physical Characterization of Remediation Cells 1, 2, and 3

There was generally good agreement between the planview and REMOTS® results in characterizing sediments within the survey area. Both techniques indicated that in terms of sediment distribution, remediation cells 1, 2, and 3 can be divided into two distinct sections. Fine-grained sediment, determined to be relic dredge material, was found predominantly within the elongated basin defined roughly by the 23-24 m depth contours. This basin is a dominant feature within all three of the remediation cells. Outside the 23 to 24 m contours, sand and coarser material was found, especially on the steeper sloped banks represented by the closely positioned contour lines (Figure 3-7).

Both the planview and REMOTS® analyses indicated an association between water depth and sediment type. Coarse-grained sediments (i.e., sands and gravel) were found across a range of depths from 16 to 23 m, and with only five exceptions, all stations within the 24 m depth contour contained silt-clay (>4 phi; Figure 3-7). Of the five exceptions, three grain sizes were 4 to 3 phi (very fine grained sand) and one station had a grain size of
<-1 phi, possibly due to construction rubble deposited in the past. In this part of the New York Bight, bottom areas above a critical depth of roughly 20 to 21 m apparently experience wave energy from periodic storm events which is high enough to cause selective winnowing of the fine-grained fraction and bedload transport of the remaining coarser grained sediments (SAIC 1996a and b). Areas below 21 m experience significantly less bottom energy and are generally quiescent, favoring the accumulation of fine-grained sediments, as observed in this survey at stations below the 24 m depth contour.

Given the strong association between depth and bottom energy, it is not surprising that rippled, well sorted, fine-grained sand was found on the slopes of the historic disposal mounds in the shallower waters in the northeast corner of the survey area. At one time, soon after their formation, these mounds probably consisted of fine-grained dredge material (silt-clay). Two processes acting over time help explain why fine sand is found now. First, wave-induced scour of the deposited dredged material during high energy storm events resulted in selective winnowing of the silt-clay fraction, leaving behind a lag deposit of coarser material (sands). Second, wave induced migration of sands from surrounding areas has acted to cover the deposit. The ripples observed in both the REMOTS® and planview images provide evidence that bedload transport of the sand has occurred on the western slopes of the historic disposal mounds in the shallower northeastern section of the survey area. These two processes also help to explain the abundance of the finer silt-clay material present within the elongated basin defined by the 24 m contour. This area apparently experiences relatively little storm-induced disturbance, allowing the fine-grained, historic dredge material to accumulate and remain on the sediment surface.

The western most side of the rectangular survey grid, adjacent to remediation cell 2, had consistently larger grain size in the range of 2 to 1 phi. In addition, the southern most end, located south of remediation cell 3, had sand with a grain size of 3 to 2 phi. These two areas are both located on the edge of the HARS buffer zone approximately 3 km away from the former Mud Dump Site, and the sand is probably native sediment.

4.2 Distribution of Dredged Material in Remediation Cells 1, 2, and 3

The disposal of dredged material at the Mud Dump Site had been regulated by NYD and Region II of the EPA since the site was officially designated in 1984. Prior to this, disposal of dredged material and construction waste had been occurring in the New York Bight for nearly a century and was poorly regulated. As a result, deposits of dredged harbor sediments and construction material (i.e., cellar dirt) can be found throughout the HARS, as documented in baseline bathymetric, REMOTS® imaging, planform photography, and side-scan sonar surveys conducted in 1995 and 1996 (SAIC 1996a, b and c).

In the current survey of remediation cells 1, 2, and 3, brick fragments and other forms of cellar dirt were found at 16% of the stations (26 of the 158 surveyed). Most of the stations containing the cellar dirt were located just west of the two historic dredge mounds in the northeastern corner of the rectangular survey grid. A relatively small area of fresh dredged material was found in the center of remediation cell 1 surrounding station E-1600 (Figure 3-9). This was a direct result of the Passenger Ship Terminal dredging project carried out in March and April, 1998. The main distinguishing feature of this material was its lighter gray color and softer texture, determined from the photographs and camera prism penetration; it was clearly distinguishable from the relic dredged material as illustrated in Figure 3-11.

Most of the dredged material found during this survey was located within the basin defined by the 23-24 m depth contours. The main distinguishing feature of this material was its highly-reduced (black) appearance below the RPD (Figure 3-10); most of the material is presumed to be relic dredged material resulting from historic disposal. Two mechanisms are proposed to explain the presence of this material in the basin. First, the material may have been deposited directly in this area in the past. Second, the deep basin probably represents a focusing site for accumulation of fine grained sediments originally deposited elsewhere. Specifically, it is reasonable to assume that over time, the fine grained sediments being winnowed from the shallow tops of nearby historic disposal mounds during storm events have settled and accumulated within the basin. In particular, the northern section of the basin is located downslope from the large historic disposal mound found to the east of remediation cell 1, while the central part of the basin is downslope from the historic disposal mound found to the east of remediation cell 2. The October 1995 REMOTS® survey indicated that fines had been winnowed from the tops of these historic mounds and deposited on the mound flanks to the west, in the direction of the basin (SAIC 1996a). The predominant low-frequency bottom currents in this region are toward the southwest (Freeland et al., 1981), further supporting the idea that fine-grained sediments transported from the historic disposal mounds may have been deposited within the basin.

4.3 Benthic Habitat Characterization of Remediation Cells 1, 2 and 3

The REMOTS® Organism Sediment Index (OSI) is designed to provide an overall summary of benthic habitat quality. Experience has shown that OSI values greater than or equal to +6 are indicative of relatively healthy or unstressed benthic habitats. In the August 1998 survey, the highest benthic habitat quality was found at stations comprising the northeast and southwest corners of the rectangular sampling grid (Figure 3-18). These stations were located on sloping bottoms representing the sides of the basin, above the 24 m depth contour, where rippled sands were the dominant sediment type. These stations were generally devoid of any dredged material within the measurable sediment depth. The high OSI values reflect relatively deep (>3.75 cm) RPD depths and the presence of surface worm tubes (Stage I organisms).

Within the 24 m depth contour, evidence of Stage III organisms was found in the REMOTS® images at only one station (Figure 3-15). In the absence of extensive sediment bioturbation by large-bodied, head-down deposit-feeding, Stage III organisms, RPD depths within the basin have remained relatively shallow (Figure 3-17). The combination of shallow RPD depths and the presence of only surface-dwelling Stage I organisms is reflected in low to intermediate OSI values of between 0 and +6 at the majority of stations. These relatively low OSI values are indicative of poor or degraded benthic habitat quality.

Long-term REMOTS® monitoring at the Mud Dump Site has shown that Stage III organisms typically become well-established in organic-rich, fine-grained dredged material within a few years of its placement. The absence of Stage III organisms in the relic dredged material of the basin within remediation cells 1, 2 and 3 indicates an anomalous pattern whereby the expected succession from Stage I to Stage III has not occurred. In studies performed in support of the Environmental Impact Statement for the HARS designation, sediments collected at several stations within and near the elongated basin were found to have both elevated chemical contaminant levels and significant toxicity in the standard 10-day amphipod test (U.S. EPA 1997). Therefore, the most likely explanation for the anomalous benthic successional pattern observed in the baseline REMOTS® survey is the continuing elevated levels of chemical contaminants in the relic dredged material and concomitant toxicity to resident benthic organisms. The August 1998 REMOTS® results indicating degraded benthic habitat quality within major portions of remediation cells 1, 2 and 3 therefore are consistent with the earlier EIS findings (based on studies conducted between 1991 and 1995) showing elevated contamination levels and significant toxicity in the same general area.

The August 1998 REMOTS® survey showed that Stage I organisms were distributed throughout remediation cells 1, 2, and 3, particularly within the basin where much of the fine-grained relic dredged material is presumed to be contaminated and toxic (Figure 3-15). The Stage I organisms consisted largely of surface-dwelling, tubicolous polychaetes (e.g., Figure 3-16a). Because many of these organisms are suspension-feeders, they do not have extensive exposure to the underlying contaminated sediments. In addition, common Stage I polychaetes like the capitellids and spionids are generally characterized as pollution-tolerant opportunists with high rates of population turnover. These groups apparently are able to maintain populations within the basin because they inhabit a relatively narrow, oxygenated zone at the sediment surface and feed primarily on suspended material in the overlying water. Infaunal organisms having intimate contact with the sediment, particularly head-down, deposit-feeding Stage III organisms, apparently are not able to maintain viable populations within the contaminated relic dredged material of the basin.

Individuals of what is assumed to be the burrowing anemone *Ceriantheopsis americanus* were observed in the REMOTS® images at a number of stations within the elongated basin (Figures 3-15 and 3-16b). Accumulations of shells, representing possible death assemblages of the nut clam *Nucula proxima*, also were observed at the sediment surface in images throughout the basin (Figures 3-15 and 3-16c). It is interesting to note that in the New York Bight, *Ceriantheopsis americanus*, *Nucula proxima*, and several polychaetes are among the species reported to be most indicative of fine-grained habitats with high total organic carbon and elevated contaminant levels (Chang et al. 1992). The dead shells of *Nucula* (and perhaps other bivalve species) observed at the sediment surface throughout the basin may represent the remains of populations which were able to become established within the basin only for limited periods of time before experiencing contaminant-related mortality.

4.4 Comparison with Previous Surveys

As previously indicated, SAIC performed REMOTS® surveys in October 1995 and May 1996 in areas surrounding and overlapping HARS remediation cells 1, 2, and 3 (Figure 4-1). It is interesting to note in Figure 4-1 that very few of the stations from the 1996 survey were located in remediation cells 1, 2 or 3, and the stations from the 1995 survey do not provide very uniform spatial coverage in any of the three cells. Given this lack of uniform coverage, the results from the two previous surveys are considered to be of limited use as a baseline for future HARS monitoring. The even station spacing used in August 1998 provides much more uniform coverage within each of the three cells and the

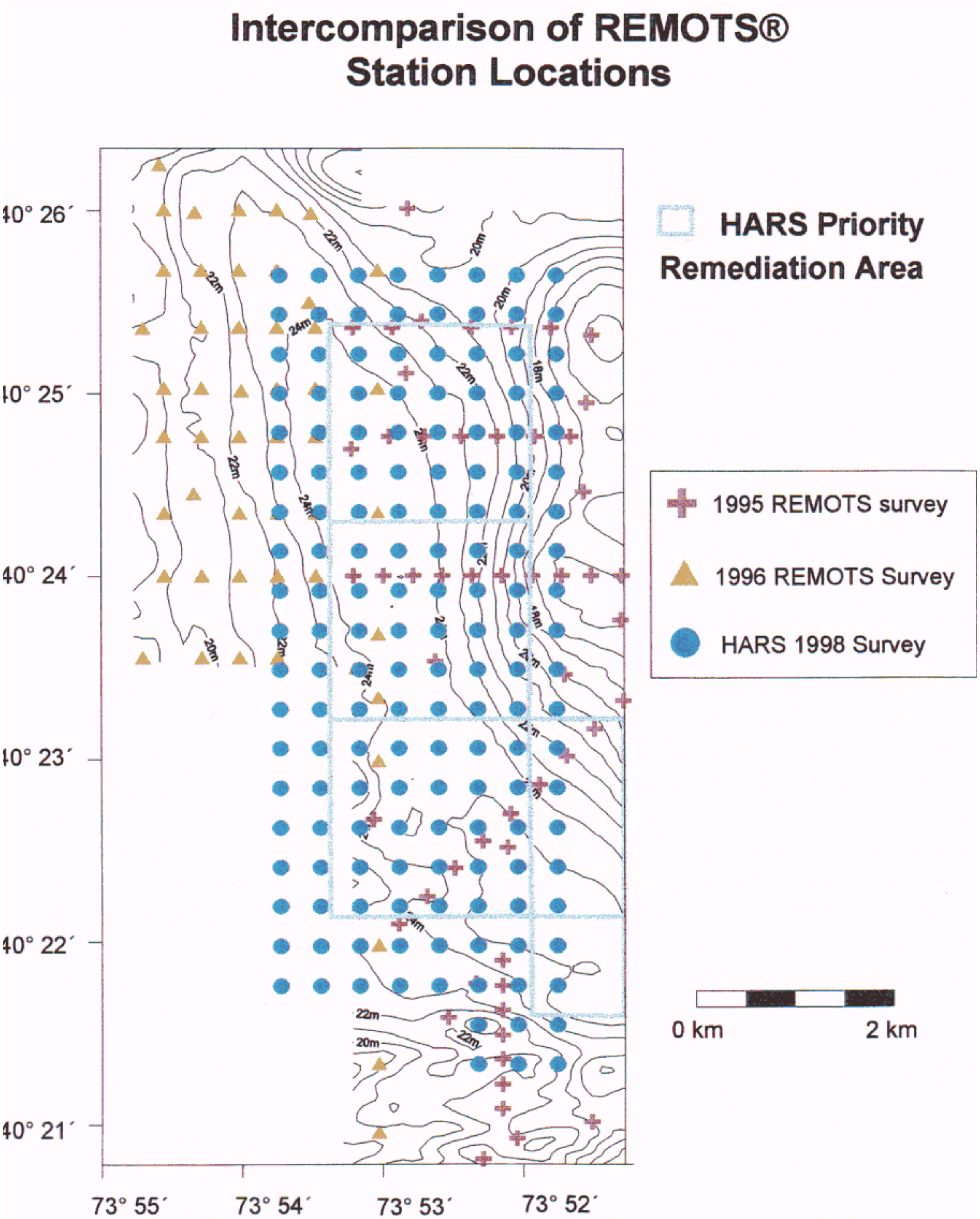


Figure 4-1. Map of station locations for the 1995, 1996 and 1998 REMOTS® surveys.
surrounding buffer zone, thereby providing a more acceptable baseline for use in future comparisons.

The most significant area of overlap between the previous two surveys and the present one was in the elongated basin defined by the 24 m depth contour. In all three surveys, the majority of stations within the basin were found to have relic dredge material present and small scale boundary roughness values of less than 2 cm. These stations also had consistently shallow (i.e., less than 3 cm) RPD depths over the three surveys. In the 1995 survey, Stage III was present at 66% (8 of 12) of the REMOTS® stations in the basin. In the 1996 survey, only 25% (2 of 8) of the stations within the basin had Stage III present.

The August 1998 REMOTS® survey yielded an extremely low percentage of stations (1 of 41 or 2%) with Stage III present. These results suggest that while Stage III may have been detected in past surveys, populations of these organisms within the basin apparently are not widely distributed or long-lived, probably as a result of the elevated contaminant levels. Generally, all three surveys have shown low to intermediate OSI values at stations located within the central part of the elongated basin, indicating degraded benthic habitat quality in this area.

4.5 Evaluation of Candidate Reference Areas

It is expected that future assessments of changes following the completion of capping operations within each of the HARS remediation cells will be based on comparisons both with baseline conditions (i.e., before/after comparisons) and with conditions in nearby reference or control areas (i.e., control/impact comparisons). This so-called “BACI” (Before-After/Control-Impact) sampling design is one which is commonly employed in environmental monitoring studies (Underwood 1992, 1994). As previously stated, it is generally considered desirable to have multiple reference areas located near and having characteristics similar to the impact area, while being far enough away so as not to experience the impact. Since the HARS presently encompasses both fine-grained and sandy areas, and both sand and silt-clay eventually may be used for capping at different times and in different locations, it appears desirable to identify both sandy and fine-grained reference areas to facilitate future comparisons. The following provides an evaluation of each of the candidate reference areas sampled during the August 1998 survey.

SREF

The South Reference Area (SREF) is predominantly sandy and has been utilized since at least 1993 for monitoring of both the 1993 and 1997 Capping Projects at the Mud Dump Site. In the August 1998 REMOTS® survey, OSI values at SREF reflected relatively deep RPD depths and the continuing presence of Stage I organisms. This area was considered to have good overall benthic habitat quality, which is consistent with the results of numerous previous REMOTS® surveys. It is assumed that some portion of the remediation material used for capping at the HARS will be sand, and that once this sand is in place, its biological and chemical characteristics will need to be compared with those of nearby areas which are both sandy and undisturbed. Because the SREF area meets these criteria, it is recommended for use in future HARS monitoring.

NREF-2, NY-6 and R-2

Candidate reference areas NREF-2, NY-6 and R-2 are evaluated here as a group because they are in close proximity to each other and appear to share similar habitat characteristics. All three areas are located in or near the Christiaensen Basin to the north or northeast of the HARS, and all three were found to have predominantly fine-grained sediment (either silt-clay or very fine sand with a significant silt-clay fraction). The sediment below the RPD was black in all three areas, and it was deemed likely that all three have experienced inputs of sewage sludge from the nearby Sewage Sludge Disposal Site. In all three areas, RPD depths were generally shallow (< 3 cm), and there was a notable absence of Stage III organisms. This resulted in OSI values ranging from 0 to +6, which generally indicate degraded or stressed benthic habitat conditions in the three areas.

Candidate reference area NREF-2 was selected initially as a possible replacement for the sandy reference area NREF, which was used extensively along with SREF in previous monitoring efforts at the Mud Dump Site. It was expected that sand would be found at NREF-2, but finer-grained sediments were observed in the August REMOTS® survey. This is probably related to the location of this area near the western edge of the Christiaensen Basin, a broad topographic depression where fine-grained sediment is known to accumulate. Because NREF-2 did not prove to be sandy, it may be desirable to sample additional locations in future REMOTS® surveys in order to identify a second sandy reference area.

Both NY-6 and R-2 were sampled extensively in the 1986 to 1989 NOAA study of environmental changes following the cessation of sewage sludge dumping at the 12-mile site (NOAA 1995). It was found that both stations had elevated chemical contaminant levels attributed to inputs of sewage sludge, and, in general, sludge contamination was present at several sites in depositional areas of the Christiaensen Basin. Therefore, while the fine-grained sediments at reference areas NREF-2, NY-6 and R-2 are considered to be a positive feature, each area also appears to have stressed or degraded benthic habitat conditions which may be related to chemical contamination from past sewage sludge disposal.

The contaminant-related degradation of benthic habitat conditions at these three candidate reference areas is very similar to that observed within the elongated basin in HARS remediation cells 1, 2 and 3. Based on this similarity, it is possible that one or more of these candidate reference areas might serve as a useful “negative control” in future HARS monitoring. As remediation proceeds, it may prove valuable to compare conditions at the HARS with those found in one (or more) of these nearby degraded areas that is not being remediated. Future assessments of the success of remediation would be based in part on testing whether or not benthic habitat conditions within the HARS have become significantly different from those in the degraded reference area(s).

Additional study of candidate reference areas NREF-2, NY-6 and R-2 is needed before any decision is made to designate one or more for use in long-term HARS monitoring. In particular, it is recommended that each area be characterized with respect to sediment chemistry and benthic community structure to determine its degree of similarity to current conditions at the HARS. Sediment chemistry testing in particular would help to confirm whether these areas have been degraded due to past inputs of sewage sludge, as suspected based on the NOAA study and the REMOTS® results presented here. Any one of the three areas would be useful as a reference only if it has sediment chemical and biological conditions very similar to those currently found within the HARS.

DEEP-REF

As previously indicated, candidate reference area DEEP-REF is located at a depth of roughly 60 m (197 ft) within the Hudson Canyon. It was sampled based on the expectation that fine-grained sediments would be found, and, in fact, very soft silt-clay was observed to be the dominant sediment type in this area. In the absence of nearby anthropogenic sources, this fine-grained sediment was assumed to be naturally-occurring. It had a dark color below the redox layer, suggesting high organic content. This resulted in relatively shallow RPD depths, but all stations except two appeared to have well-developed Stage I on III benthic communities. Organism-Sediment Index values were greater than +6 at most of the stations, indicative of good overall benthic habitat quality.

Based on these results, DEEP-REF is an area which represents a potential “positive control” for use in future HARS monitoring. Areas of the HARS which are remediated with fine-grained sediment eventually might be expected to become similar to DEEP-REF in terms of overall benthic habitat quality. However, use of the DEEP-REF area may be constrained because it is so much deeper than the HARS. As a result, physical oceanographic conditions at DEEP-REF are probably significantly more quiescent than those at the HARS, which together with the greater depth may result in significant differences in chemistry and/or benthic community structure. Further sampling of DEEP-REF would be needed to characterize present chemical and biological conditions and determine the degree of similarity with conditions currently existing at the HARS.

5.0 SUMMARY

The first objective of the August 1998 REMOTS® survey of the HARS was to characterize physical and biological seafloor conditions and assess benthic habitat quality in and around remediation cells 1, 2 and 3, prior to the commencement of capping operations expected to occur over the next several years. The second objective was to characterize seafloor conditions in several candidate reference areas and evaluate their suitability for use in future monitoring efforts.

Results of bathymetric surveys performed in 1995 and 1996 showed that the dominant topographic feature within remediation cells 1, 2 and 3 is an elongated topographic depression defined roughly by the 23 to 24 m depth contours. Analysis of REMOTS® images and planview photographs indicated that silt-clay was the dominant sediment type within this basin. On the sloping bottom which represents the sides of this elongated basin, a mixture of coarser-grained sediment types, including rippled sand, gravel and rocks, was found.

The silt-clay found within the basin was presumed to be relic dredged material resulting from historic disposal. The main distinguishing feature of this fine-grained material was its highly-reduced (black) appearance below the redox layer. The material may have been deposited directly in the basin in the past, or it may have eroded from shallow disposal mounds located nearby and gradually accumulated within this topographic depression over time. A relatively small area of fresh dredged material was found near the center of remediation cell 1; this material was placed in this location during the Passenger Ship Terminal dredging project carried out in March and April, 1998.

The highest benthic habitat quality was found at stations located on the sloping bottoms representing the sides of the basin, above the 24 m depth contour, where rippled sands were the dominant sediment type. These stations were generally devoid of any dredged material within the measurable sediment depth. Relatively high Organism-Sediment Index values (> +6) at these stations reflected deep RPD depths (>3.75 cm) and the presence of surface worm tubes (Stage I organisms).

Within the basin, surface-dwelling Stage I organisms were dominant, and there was a notable absence of Stage III organisms. In the absence of extensive sediment bioturbation by infaunal Stage III organisms, RPD depths within the basin were relatively shallow. The combination of shallow RPD depths and the presence of only surface-dwelling Stage I organisms resulted in low to intermediate OSI values of between 0 and +6 at the majority of stations. These relatively low OSI values are indicative of poor or degraded benthic habitat quality.

The HARS Environmental Impact Statement studies conducted between 1991 and 1995 found elevated contamination levels and significant toxicity at stations located within the basin. The absence of Stage III organisms within the basin observed in the August 1998 REMOTS® survey therefore was attributed to the continuing toxic effects of chemical contaminants. It was hypothesized that surface-dwelling Stage I organisms are able to maintain viable populations within the basin because they do not have the same extensive exposure to the underlying contaminated sediments as deposit-feeding, Stage III infauna.

The South Reference Area (SREF) was found to be predominantly sandy and had good overall benthic habitat quality, consistent with the results of numerous previous REMOTS® surveys. It was recommended that this area continue to be used as a sandy reference in future HARS monitoring.

Candidate reference areas NREF-2, NY-6 and R-2 located in the Christiaensen Basin to north and northeast of the HARS were all found to have fine-grained sediment. The sediment below the RPD was black in all three areas, and it was deemed likely that all three have experienced inputs of sewage sludge from the nearby Sewage Sludge Disposal Site. Relatively low OSI values in these areas were indicative of degraded or stressed benthic habitat conditions. It is possible that one or more of these candidate reference areas might serve as a useful “negative control” in future HARS monitoring, but additional chemical and biological characterization of each area is needed before any final decisions can be made.

Candidate reference area DEEP-REF is located at a depth of roughly 60 m (197 ft) within the Hudson Canyon. Very soft silt-clay was observed to be the dominant sediment type in this area, and Organism-Sediment Index values greater than +6 indicated good overall benthic habitat quality. The DEEP-REF area represents a potential “positive control” for use in future HARS monitoring. However, use of the DEEP-REF area may be constrained because it is so much deeper than the HARS, and further chemical and biological sampling is recommended.

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